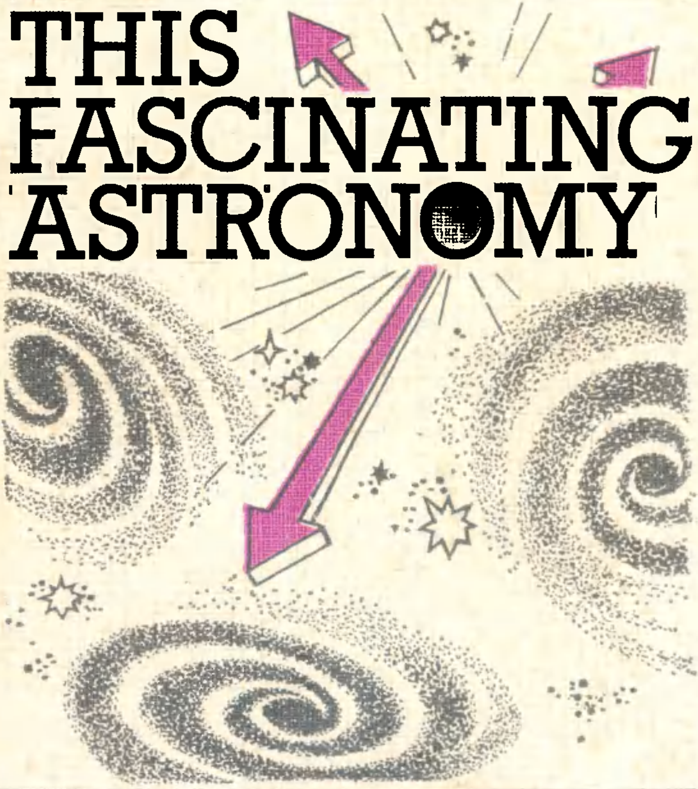
SCIENCE FOR EVERYONE

V. N. KOMAROV

# THIS FASCINATING ASTRONOMY



MIR

В. Комаров

# Новая занимательная астрономия

Издательство «Наука», Москва

V. Komarov

# This Fascinating Astronomy

*Translated from the Russian*
*by* N. Kittell

Mir
Publishers
Moscow

First published 1985
Revised from the 1983 Russian edition

*На английском языке*

# Contents

Preface

## Chapter 1. What Is Fascinating in Astronomy

## Chapter 2. The Solar Family

## Chapter 3. Deep in the Universe

## Chapter 4. What If?

# Preface

Astronomy is as revealing as it is fascinating. Emerging among the first sciences at the dawn of civilization, it has been at the forefront of natural studies ever since.

Today astronomy is developing at a breathtaking pace. The new means of research — the radiotelescopes and the various space probes — have brought about an information explosion, giving rise to one discovery after another in the study of the universe. These discoveries cannot be overestimated — they bring us fundamental knowledge of nature and reveal the innermost laws of the structure and motion of matter.

Astronomy creates a new vision of the universe and strikingly illustrates the dialectical process of cognition of our natural environment, of progress from relative to absolute knowledge.

The author did not intend just to inform the reader of certain amazing facts but to show the dialectics of the development of scientific thought and to bring out the fact that creative thinking free of bias and the development of new, original ideas are truly the demand of our times.

But in the final analysis, the new in science, no matter how original it may seem, invariably rests on the foundation of previous knowledge. Besides, there is bound to be something in common in the methods of treatment of various scientific problems, although every one of them is unique in itself.

Therefore most of the material in this book deals with facts and concepts believed to be sufficiently proved from the point of view of contemporary astronomical science.

But since quite a number of astronomic puzzles are still awaiting solution, researchers have resorted to various and at times rather imaginative hypotheses. Very possibly, some of them will have to be discarded as our knowledge of the universe extends. It is impossible for astronomy to do without hypotheses, that is, theories that have not been confirmed but not disproved either. All the more so, since this is a science which will doubtlessly progress no less rapidly in the years to come, having to deal with more and more new facts. Hypothesizing is an essential form of the development of natural sciences.

That is why along with discussing confirmed facts the author outlines some of the more interesting speculations and conjectures associated with the study of the universe.

As Lenin noted, "Human reason has discovered many amazing things in nature and will discover still more, and will thereby increase its power over nature."[1]

As far as contemporary astronomy is concerned, here we are witnessing a process which first took place in physics (where it was even more striking): concepts are becoming more and more abstract, less illustrative and less understandable.

---

[1] V.I. Lenin, *Collected Works*, Vol. 14, pp. 281-282.

That is why in presenting his material the author has used science fiction, not a standard method in popular science literature. But science fiction has the indisputable advantage of being capable of making the most abstract ideas material and concrete.

Science fiction is a way of getting the reader interested in problems of modern astronomy, of outlining them more sharply, and making them easier to understand.

The author hopes his effort will be appreciated.

## Chapter 1

# What is Fascinating in Astronomy

We find these two words in the titles of many books in this genre —"Fascinating Astronomy", "The Fascinating and Astronomy", "Astronomy in a Fascinating Light", etc.

The titles changed as astronomy developed and knowledge grew. What seemed incredible yesterday has become common knowledge taken for granted today. The idea of what is "fascinating" has changed too.

The great revolution in the natural sciences at the break of the 20th century, and the elaboration of fundamentally new physical theories, such as the theory of relativity and quantum mechanics, have greatly extended the scientific vision of the universe, changed the very style of scientific thinking and the approach to the study of natural phenomena.

Unexpected discoveries are made more and more often, particularly in physics and astronomy, undermining many commonly accepted ideas, revealing phenomena in a new light, and refining our conceptions of the 'universe and laws governing it.

This does not mean to say, however, that the science of the near future will completely refute all modern knowledge. It would be absurd to expect anything like that. Natural sciences have the greatest achievements to their credit: many of the fundamental laws they have established have been widely applied in practice. This is the golden fund of natural science which will retain its meaning in the face of any "scientific upheaval". While never stopping in its advance, science invariably bases itself on the sum-total of amassed knowledge. Even though revolutions do occur in science giving rise to new concepts, previous fundamental knowledge is incorporated in them as composite parts retaining their significance for a definite set of phenomena and conditions.

This fact granted, it must be stated that modern science is associated with the extraordinary in large measure. Extraordinary ideas undermine accepted notions, questions are treated from unexpected angles, unconventional views are taken of conventional things, problems find extraordinary solutions, incomparable things become comparable, amazing conclusions are drawn from generally known facts and, new phenomena are discovered completely overturning our accepted knowledge.

The path of science lies through contradiction and paradox. Let us look up the word "paradox" in the *The Great Soviet Encyclopaedia*. It says: "Paradox, phenomenon or assertion contrary to accepted notions of what is reasonable or possible".

Paradoxes are different. They may reflect real or seeming contradictions. But whatever the case, a paradox is always a contradiction.

Lord Caversham in Oscar Wilde's play *An Ideal Husband* makes a significant statement: "That is a paradox, sir. I hate paradoxes."

It is easy to see why the esteemed Lord feels such revulsion for paradoxes. Any contradiction is bound to upset the regular arrangement of ideas and requires elucidation. In Lord Caversham Oscar Wilde ridiculed the stubborn traditionalism and conservative thinking of a certain section of English gentry who would not burden themselves with excessive thinking but firmly put aside anything that was not clear or was out of the ordinary.

But a paradox is not to be ignored easily, for it is something man comes up against in absolutely all spheres of his activity. A paradox defies common sense, astonishes and strikes the imagination. Is the saying "Slow and steady wins the race" not paradoxical? And it requires a certain effort to see its meaning.

A special case are logical paradoxes, or sophisms, that is, arguments that are perfectly logical but lead to contradictory conclusions about which it is quite impossible to decide whether they are true or false. Sophisms have come to us from ancient Greek philosophers.

One man said, "Everything I say is false". Therefore his statement was also a lie. But this means that what he said was true. But if what he said was true then he lied, and so on.

Or take the well-known fable about a sage who was to be executed. The judge allowed him to make his last statement and said that if he told the truth he would be hanged and if he told a lie he would be beheaded. Without a moment's thought the sage exclaimed, "I shall be beheaded". The execution was put off. If they had hanged the sage, it would mean that he had told a lie and then he should have been beheaded. But if he had been beheaded it would mean that he had told the truth and he should have been hanged...

In both cases perfectly logical reasoning containing no errors leads to contradictory results which cannot be considered either true or false.

Incidentally, the paradox is not in the fact that we are following a vicious circle of contradictory reasoning but in the fact that along the lines of strict and unerring formal logic, which only accepts "yes" or "no" for an answer, situations might arise where it is impossible to say either "yes" or "no". Apparently, there is a fundamental fallacy in the initial postulates themselves. Curiously enough, it has not been possible so far to establish how such paradoxes are evolved.

Paradoxes play a singular role in the development of science. Academician Leonid Mandelstam, a prominent Soviet physicist, used to say that there are two levels of understanding of a problem. The first is when the given set of phenomena has been studied fairly well and everything related to it seems to be reasonably well established. And if a new question in this field arises, it may baffle one. The second level of understanding is perception of the general picture, a clear understanding of all the connections, both internal and external.

Very often the transition from the first to the second higher level involves certain paradoxes and contradictions that have to be overcome.

The well-known French physicist Carnot, for instance, maintained that there was a constant amount of heat in nature and that it only flowed from one level to another. But soon another physicist, Joule, proved by experiment that heat could be generated anew as the result of work done. The two concepts were plainly in contradiction. Efforts to solve this contradiction resulted in the development of modern thermodynamics, the science of heat processes.

It is also well known that the contradictions and paradoxes that were not settled within the framework of classical physics resulted in the elaboration of the theory of relativity and later, of quantum mechanics. The modern picture of the universe also unfolds directly through overcoming major paradoxes.

Modern astrophysics has naturally had its share of paradoxes to deal with. Of late years a series of unusual objects and phenomena have been discovered in deep space — a cosmic residual background radiation which confirms the theoretical conclusion that the Metagalaxy was formed as a result of the "big bang"— an explosive disintegration of a super-dense clot of plasma; quasars, sources of tremendous amounts of energy; pulsars, sources of pulsating radiation which have hypothetically been included in the range of neutron stars; explosive processes in the nuclei of galaxies; X-ray sources; hydroxyl emissions and many others.

It is only logical to suppose that these surprises revealed by space studies are a first signal that it is necessary to "improve" our conceptions of matter and the universe, although it is still too early to assert that new astronomical discoveries are bound to cause a revolution in physics.

Academician Vitali Ginzburg, a well-known Soviet physicist, writes: "According to most astrophysicists, it may still prove possible to explain the extraordinary phenomena observed in the universe without resorting to fundamentally new concepts... On the other hand, the nuclei of galaxies and quasars are precisely the objects where deviations from accepted physical laws are most likely."

Contradictions and paradoxes can also play a less spectacular role in science. This happens when they enable scientists to obtain a more accurate picture of a phenomenon, to see through the maze of inner connections of a process and refine our methods of cognition of nature.

In short, it is worthwhile to take a look at a phenomenon of the external world from an unusual angle and try to see it in a new way and not through the prism of conventional ideas.

This brings to mind the words of the well-known American SF writer, Robert Sheckley: "Some men feel that the height of intelligence is the discovery that all things may be reversed, and thereby become their opposites. Many clever games can be played with this proposition..."[1]

To this we must add that such games are not only clever but also very useful and not only to the astronomer, physicist or chemist but to any creative worker — writer, artist, and engineer — and in general, any inquiring mind.

When asked his opinion about what qualities should make an engineer, a well-known designer answered almost in Sheckley's words: "A real engineer must not only have a clear understand-

---

[1] Robert Sheckley, *Mindswap*, New York, 1967, p. 145.

ing of a phenomenon, he must also know how to turn it inside out."

It is not enough to study a phenomenon from a text-book, to learn by heart the relevant laws and mathematical formulas. It is essential to be able to treat it from different angles and to be able to imagine what happens if it does not follow its usual pattern. Even more important, one must be prepared to expect it to follow a different pattern.

The outstanding contemporary American physicist, Richard Feynman, writes[1]:

"... A philosopher once said, 'It is necessary for the very existence of science that the same conditions always produce the same results.' Well, they do not. You set up the circumstances, with the same conditions every time, and you cannot predict behind which hole you will see the electron. Yet science goes on in spite of it — although the same conditions do not always produce the same results... In fact it is necessary for the very existence of science that minds exist which do not allow that nature must satisfy some preconceived conditions..."

This book is intended to give an idea of what is unusual in modern astronomy. On the one hand, this includes elucidation of new facts that are unusual from the point of view of traditional conceptions and on the other, examination of generally accepted knowledge in a new light. Some of the material deals with original hypothetical speculations and with issues on

---

[1] Richard Feynman, *The Character of Physical Law*, London, 1965 pp. 147-148.

which a lively astronomical debate is currently focused.

Modern science, particularly astronomy, is making a bold plunge into the unknown. Just as the boundary between abstract theories and practical application is levelled out in our day so is the boundary between science and science fiction. On the one hand, modern science itself treats the most staggering hypotheses with commendable tolerance and patience and on the other, science fiction is a field where most incredible ideas may be set out and discussed more freely than in "official" science, provided these ideas contain a grain of realism. Perhaps this latter fact explains why today science fiction attracts not only writers but also many professional scientists. Science fiction has yet another advantage — it makes many perfectly real but seemingly inconceivable ideas more graphic, more clearly defined and easier to understand.

When dealing with outstanding problems of modern astronomy we shall also have recourse to science fiction.

The world into which this book is introducing you is mostly astronomical. But this world has other sciences working along its borders — physics, mathematics, biology and chemistry. The multitude of border issues is a characteristic feature of modern science.

But before we start I should like to quote Sheckley once more: "It is conceivable that nothing whatsoever will happen to you in the Twisted World. It would be unwise to expect this, and equally unwise to be unprepared for it" ... "The comments concerning the Twisted World may have nothing to do with the Twisted World. The traveller is warned."[1]

The book you are going to read is far from being a comprehensive outline of modern astronomy or any of its departments. *It is not a popular* version of a systematic course in astronomy. It deals with certain questions of the study of the universe, which are interesting in the light of the notion "fascinating" which we discussed at the beginning.

The author employs as few calculations and formulas as possible, for he considers it his main task, without claiming any particular consistency, to try to reveal the qualitative aspects of astronomical phenomena and the specifics of their study.

## Negation, the Beginning of Everything

Strange as it may seem, a good half of scientific discoveries begin with negation.

Are the two extremes — the positive and negative — mutually exclusive? Is not the positive sometimes born of the negative? And is the role of the negative really negative in science? Or, perhaps, it is positive?

This play of words contains a serious idea. Any scientific theory has its own borders, defining the range of phenomena and conditions it describes fairly well, that is, defining the limits of its applicability. Any theory is bound to be limited and is powerless to encompass the infinitely diverse phenomena occurring in nature.

---

[1] Robert Sheckley, *Op. cit.*, pp. 144-145.

True, according to one point of view, the whole diversity of nature can in principle be described by a finite number of fundamental laws. This view can hardly be fully justified. Nothing has been discovered so far to prove it. The history of natural sciences rather points to the opposite.

Thus even the most general theory has its limits of applicability. Sooner or later new facts lying beyond these limits are discovered, causing negation of accepted ideas. It is from this negation that a new, more general theory will evolve.

But it must not be assumed that the new theory will completely reject previous knowledge. On the contrary, it will assimilate it as a special, limiting case. The old theory will remain fully valid within the sphere where it is supported by facts. In this lies the principle of conformity, one of the fundamental principles of contemporary physics.

The old theory, far from being discarded, becomes much more valid. First, its postulates are now applied within more precisely defined limits, hence it becomes more reliable. Second, its importance stems not only from its own merits but also from the merits of the more general theory of which it has now become a special case.

In this way, the new theory rejects previous "misconceptions" and not previous knowledge.

For example, it was considered in the age of classical physics that the laws of mechanics were applicable to all natural phenomena without exception. It was a misconception and it was that misconception and not Newtonian mechanics that suffered a blow from the theory of relativity. As for classical mechanics itself, it became a special case of the theory of relativity, true for speeds that are much lower than the speed of light and for masses that are not too large. That is why mechanics has not only retained its significance but become much more precise.

It is evident, therefore, that negation often provides the basis on which scientific progress rests.

It is for good reason that the quest for the new is intense particularly in fields where there is reason to expect the discovery of basically new information.

"... But experimenters search most diligently, and with the greatest efforts, in exactly those places, where it seems most likely that we can prove our theories wrong", Richard Feynman writes. "In other words we are trying to prove ourselves wrong as quickly as possible, because only in that way can we find progress."[1]

Negation is inevitably preceded by doubt. According to Richard Feynman, doubt is an indispensable component of developing science, a prerequisite of scientific knowledge: either we leave the door for our doubt open or no progress will be made. There is no cognition without questioning, there is no questioning without doubt.

These then are the landmarks on the path of scientific progress: new facts — doubt — negation of accepted notions — postulation of a more general theory. Negation is a crucial stage on this path.

---

[1] Richard Feynman, *Op. cit.*, p. 158.

Thus new facts contradicting accepted ideas play a constructive and not a destructive role and contribute to more generalized, hence, more profound knowledge.

Astronomy is a science which has been particularly honoured with new discoveries these last few decades. It owes this fact, above all, to the improvement of telescopes and the development of new effective methods of research — radioastronomy, infrared, X- and gamma-ray and ultraviolet astronomy, as well as to the opportunities offered by space flights and the use of space probes.

Another important factor is that before our very eyes outer space has become a priceless source of new scientific information, the significance of which reaches far beyond the limits of pure astronomy.

The processes taking place in the boundless expanses of the universe do not occur here on earth and we have not been able to study them yet. We have come up against countless forms and states of matter, discovered hitherto unknown sources of energy and unknown physical conditions.

Contemporary physics has reached a stage where practically every new step requires highly sophisticated experiments that can be carried out by means of ever more powerful and complex equipment. Such equipment is very costly and takes years to be mounted. But this is not all. Modern physical research as a rule consists in experimental verification of certain theoretical postulates. The possibility that the experiment will yield something absolutely unforeseen and unexpected is very small and it diminishes with every passing year. Gone is the notion of "free" physical experimentation of the good old classical period.

It is another thing if we extend our search into the universe, a field for boundless experimentation, where the promise of a new discovery is very real. However, in this field too much depends on our technical wherewithal (we are not adequately equipped to observe all phenomena of outer space yet), and on our theoretical knowledge (we can observe something unique and not notice it).

This does not mean to say that physics has nothing else to busy itself with here on earth and that the one thing left for it to do is to concentrate every effort on the study of space. The physics of the earth and the universe must complement each other. But with the present rate of development of natural sciences we can well expect the universe to become a major source of priceless information capable of dramatically advancing all our physical concepts.

It is not so easy to extract new facts from the laboratory of outer space. The biggest difficulty is presented by the vast distances separating space objects from our planet. Other difficulties are almost as formidable.

## "Black Boxes" in Space

The problem of the "black box" comes from cybernetics. A "black box" is an object whose arrangement is unknown to us. It has "inputs" and "outputs", and it reacts in a certain way to certain external influences impressed on its "inputs".

Our task is to get an understanding of the arrangement of the "black box" without opening it, by merely studying its "inputs" and "outputs".

Suppose you do not know how your wireless is built and on what principles it works. You only know that the aerial feeds electrical signals into its "input" and the speaker at its "output" reproduces speech, music, and so on. You must get an idea about its arrangement by the knowledge you have of its "input" and "output".

There are two basic ways to solve your problem. You can register the signals coming through the aerial and compare them with what occurs at the "output". This way is the way of observation. The other, more active one, is the way of *experimentation*. You can feed different signals into the "input" yourself and observe what happens at the "output".

Obviously, the second way is more effective because it enables you to verify all the hypotheses and speculations concerning the arrangement of the "black box". Having studied the laws of connections between the "inputs" and "outputs" you will be able, in principle, to build a model explaining the arrangement of the "black box" with sufficient accuracy.

Astrophysicists are concerned with much the same problems. Most of the space objects are "black boxes" whose structure, or in this case, the physical processes occurring in them, can be studied only by their outward manifestations.

The astronomers' job, however, is made even more difficult by at least two circumstances.

First, they are unable to experiment and have only the way of observation open to them. Second, most "black boxes" in space are "boxes" without "inputs", or more correctly, we do not know them yet. We do not know, for instance, any external force or forces which could change physical processes occurring on the sun. True, there is one imaginative hypothesis (E. Brown's) which explains the periodic changes in solar activity by gravitational disturbances caused by the planets. But it is still only a supposition.

As for some other space objects, the importance of external forces acting on them has been confirmed. For example, curious phenomena have been registered in the binary star systems, that is, systems consisting of two stars revolving around a common centre of mass. If one of the stars is massive enough, hence, possesses a powerful gravitational field, then, according to modern astrophysics, mass transfer, whereby matter from the second "normal" star "flows" onto the first, should take place. This process can be regarded as an "input".

Furthermore, we have some knowledge of the "inputs" of planets and comets. In the case of the planets, one of the "inputs" is the effect of solar activity and in the case of the comets, it is the influence of solar heat, radiation and solar wind, and the attraction of big planets.

In solar research contemporary astronomers have only one feasible way — to register phenomena occurring in the sun's outer atmosphere — at the "outputs" of this "black box".

## Do Not Believe Your Own Eyes

One difficulty which astronomers come up against in their search for new information is also common to other sciences, say, mathematics or physics. What we mean by this is how well our conceptions agree with reality.

The entire history of the study of nature, particularly the history of astronomy, is a striking illustration of the fact that the "obvious" is a very bad adviser as far as science is concerned. Recall what reasoning ancient philosophers employed to prove that the universe was infinite: "Imagine that the universe has an edge and man has reached it. If he stretches out his hand, he will reach beyond the bounds of the universe, which will mean that the bounds of the material world will have also extended. It will then be possible for him to reach the new edge and beyond it once more. He can go on and on without end. And this means that the universe is boundless".

In his poem *De Rerum Natura* (*On the Nature of Things*) Lucretius wrote, "There is no end to the universe, for edges on its sides it would be bound to have."

Unfortunately such arguments will not do as a basis for serious scientific reasoning. We have no clear perception of many things, but this does not prove much. Although Lucretius's argument was not without its logic, it was based on our terrestrial conceptions we instinctively assume always to be true.

Let us recall how opposed Magellan's contemporaries were to his idea of a round-the-world voyage. Their main argument was common sense. "How can it be possible", they fumed, "for one moving along a straight line, always in one direction, to arrive at the point of departure?" To them such a possibility was absolutely ridiculous because they could not visualize it. But as we know, reality proved Magellan to be right.

The idea of antipodes was rejected much in the same way: if the earth is spherical how can people live on the opposite side? They have to walk upside down!

In the field of astronomic observations it is the obvious that lets us down wherever we turn. For example, in the daytime we see the sun and at night, the moon and the stars moving in the sky from east to west. Vision tells us that the earth is a fixed object and the heavenly bodies are revolving around it. And that is exactly what the ancients thought when they observed the stars' motions.

Today even schoolchildren know that the diurnal shifts in the positions of celestial bodies are only a reflection of the earth's motion.

Highly complicated are the apparent movements of the planets in the star-filled sky observed at long intervals. The planets move first from the west to the east, then stop suddenly and retrograde. Then, describing a peculiar loop, they again start moving east.

The looplike movement of the planets is really only an optical illusion resulting from the fact that we observe it from the earth which itself revolves around the sun. Copernicus understood this phenomenon correctly and introduced a basic methodological principle into nature study: the world may be different from what we directly observe. It is the task of science to establish the true nature of phenomena concealed behind what seems self-evident.

This principle became the basis of Copernicus's heliocentric conception of the world and in fact the basis of the whole modern natural science.

Here is another example illustrating this principle. The solar disc in the sky looks almost as small as the disk of the moon. However, this too is an illusion created by the fact that the distance of the sun from the earth is 400 times the distance between the earth and the moon. Observed from the orbit of Pluto, the most distant planet in the solar system, the sun would look just a speck in the void of space.

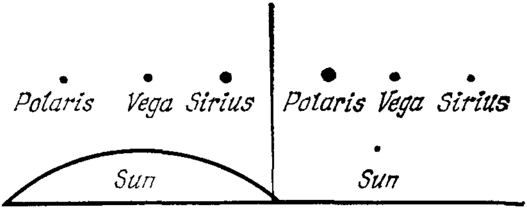
And what about the stars? We see them as tiny dots even through the most powerful telescopes, although some of them are giants millions and thousands of millions of times larger than the sun. It all depends on the distances.

The tremendous distances also correct our ideas of brightness of the stars we observe. Some stars look brighter than others. But this tells us nothing about the amount of light they really emit. Let us examine four stars we all know well: the sun, our brightest star, Sirius, the brightest star in the night sky, Vega in the constellation Lyre (four times weaker than Sirius) and Polaris, the weakest of the four (six times weaker than Vega).

If we could place the four at an equal distance from the earth, we would have to revise all our ideas about their brightness. Polaris would be the first, Vega would come next, followed by Sirius, and the sun would be the last.

In general, the appearance of a celestial body can be very deceptive. Take the moon. “Silvery” is the epithet poets have always used to describe our natural satellite. On a clear night at full moon we see all objects casting sharply outlined shadows. But in actual fact the moon is a relatively poor reflector — it reflects only about seven per cent of the sun light falling on it.

In our daily life we say that an object is black or at least dark-grey if it reflects only a tenth of the light falling on it.



Dependence of visible brightness on distance

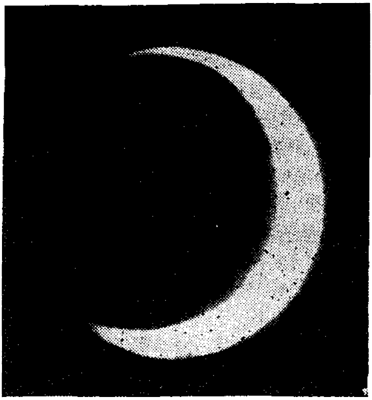
The lunar surface has been proved dark by the TV images returned by Soviet and American lunar probes, and by the direct observations of American astronauts.

But it must be noted for the sake of justice that not all lunar rocks are dark. Some are yellow and brown. The colour of the lunar surface largely depends on the angle at which solar rays hit it. According to scientists, objectively it is dark-yellow.

Why then do we see the moon on a dark sky as a luminary? Only by contrast with the black colour of the night sky.

Venus is another astronomical illusion. We have all watched this beautiful planet as the "star" of the dawn or dusk. But if we look at it through a telescope we will most likely see it as a crescent resembling a new moon.

It is only natural, since Venus is visible when it is situated away from the imaginary line connecting the earth and the sun. Therefore under no circumstances can we see the whole side of the planet lit up by the sun, even when Venus faces the other side of the sun, because then it is completely obscured by its dazzling rays.



Photograph of Venus

We see Venus as a star because distance prevents us from seeing the real Venusian crescent.

We can be deceived even during telescopic observations. The most celebrated case was the "discovery" of the Martian canals. In 1877 during the opposition of Mars the Italian astronomer Schiaparelli, who was observing Mars in his telescope, discovered a network of fine lines crossing the planet in various directions. Thus emerged the mystery of the Martian canals, followed by a period of numerous fantastic hypotheses about a highly developed civilization living on the strange ruddy planet.

But other astronomers asserted that there were no canals on Mars and that the lines were only an illusion created during telescopic observations. In reality, they said, the "canals" were scattered natural surface features which the great distance made us see as uninterrupted lines.

We observe something of a similar nature when we look at our television screen. We know that the TV picture consists of several hundred lines drawn close to one another by an electronic ray. If you come close to the set, especially if it is one with a big screen, you will see the lines clearly. But if you step back far enough, your eye will no longer see the individual lines, they will all blur into a smooth picture.

In their attempts to prove that the Martian canals were a visual deception scientists conducted interesting experiments. For example, people who had never heard anything about Mars or its canals were called into a big lecture-hall where sheets of white paper displaying random spots and dots were hung on the wall facing them. They were asked to copy what they saw.

The results proved convincing enough — those who sat in the front rows and could see the sheets very clearly, reproduced them accurately, without any additions. But those sitting in the back drew lines that were not to be found on the sheets — the distance made them see the spots and dots as lines.

Time has shown that those experiments illustrated the real state of affairs. The space probes that transmitted television pictures from a short distance to the Martian surface did not show any canals.

The areas where astronomic pictures of Mars usually showed the "canals" revealed chains of small craters and other surface features.

Often uncertainty during astronomic observations is caused by the fact that it is not always possible accurately to determine the distance to one or another space object. Objects which appear to be situated in the same area of the celestial sphere may in reality be situated at considerably different distances from the earth, hence from each other.

Some years ago American astronomers reported their discovery of isolated gas clots in our Galaxy. The nature of the motion of these clots of gas could be interpreted as evidence that a compact massive body exists in the centre of the Galaxy. Subsequent observations, however, conducted by means of the RATAN-600, the biggest Soviet radiotelescope, showed that these accumulations can hardly belong to our Galaxy but are most likely projected on its central part.

Another source of uncertainty is the fact that different physical processes in space may generate electromagnetic radiations characterized by roughly similar properties.

We could probably list many more examples and arguments proving that astronomers cannot trust their impressions or make hasty conclusions — the field of their study is too vast and complicated.

It must be borne in mind that between the physical processes occurring in an area of the universe and the conclusions of scientists observing them here on earth there lies a chain of many links. Transition from one to the next involves inaccuracies and faulty conclusions, which cannot be directly checked out as, say, in physics or biology.

Furthermore, the reading of any astronomical instrument — deflection of a pointer or darkening of film — is not in itself a scientific fact. To become such it must be reliably interpreted. And interpretation can be made only on the basis of a definite scientific theory.

"An experiment is never in the nature of a simple fact which can be stated", the French physicist Luis de Broglie wrote. "The result of an experiment always contains a degree of interpretation which means that it is a fact combined with theoretical conceptions."

And if in the given moment there are competing theories in a given field of science, then similar observational or experimental data may be given entirely different interpretations in conformity with these theories. In order to draw a reliable scientific conclusion concerning a phenomenon, this phenomenon should be examined from various angles and the results should be compared.

It goes without saying that this is as important for astronomy as it is for any other science. The difference is that in the case of astronomy the importance is crucial. For centuries the astronomer's eye had been the main instrument of astronomic studies. It was the source of all information and much depended on whether it was to be trusted implicitly or treated critically and questioned.

## Astronomers May Err Too

It is not only the human trait of believing his eyes but also common errors, that sometimes prevent the astronomer from making a correct assessment of facts and drawing a correct conclusion. Not a single science, not even mathematics, does without mistakes. As time passes, all kinds of unfortunate misprints and oversights are discovered practically in any research paper. There is a story about a scientist who decided to count the mistakes made by the authors of a hundred or so mathematical works. The critic wrote a whole book on the subject in which he himself made several hundred mistakes that were discovered later.

But there are different mistakes. Some result from carelessness but more often, from limited knowledge or from the fact that the available information on a question is inadequate. Some are unexpected mistakes. They are very hard to foresee and almost as hard to detect.

Mistakes can be instructive if they are discovered in time and if their causes are analysed carefully.

Some, twenty years ago the astronomic world was shaken by the news that the French workers at Observatoire de Haute Provence had discovered neutral potassium radiation lines in the spectrum of the dwarf star HD 117042. Potassium had never before been observed in the spectra of such stars. Subsequent spectrograms of the same star did not confirm the discovery.

But two years later a similar "potassium flare" was observed in another dwarf, HD 88230.

Intrigued by the sensational discovery, astronomers launched a systematic search, but to no avail. Probably the matter would have been dropped there but in 1965 another potassium flare was observed on yet a third star.

Sensation was in the air. This time the flare was observed on a star whose surface temperature was around 12 000 degrees. How could neutral potassium have survived such a temperature?

Another riddle was that in each of the three cases the flare was observed only once. The spectrograms that were made only a few hours later did not show a trace of the mysterious potassium. But how could the chemical composition of a star's atmosphere have changed within such a short time? For the potassium line during the flare was quite broad and intensive.

And then three Californian astronomers found an absolutely unexpected solution. The potassium lines on the spectrograms, they insisted, were not "ghosts" or "photoillusions" as in the case of the "flying saucers", but perfectly authentic lines of perfectly real potassium. Only that potassium was not on a distant star but nearby, in the observatory itself where the light of the star was falling. It was not contained in the stellar atmosphere but in the mixture of an ordinary match head. Indeed it was enough to light a match near the telescope to produce potassium lines on the spectrogram. The American scientists verified their conclusion by numerous experiments.

That was how the "match hypothesis" went down in the history of astronomy.

But perhaps the Californians were also mistaken. Because of the three astronomers who registered the mysterious "potassium flares" only two were smokers.

Another example. Relying on the results of spectral studies of the chemical composition of the atmosphere of Titan, Saturn's satellite, the only one in the solar system known to have a gaseous envelope, scientists believed until recently that it mainly consisted of methane. This prompted some of them even to suggest the possibility of organic life on Titan.

Data gathered by the American *Voyager 1* unmanned station, which visited the region of Saturn in November 1980, revealed, however, that Titan's atmosphere contains no more than one per cent of methane and consists predominantly of nitrogen (93 per cent).

How could astronomers make such a mistake? It was established that the structure of Titan's atmosphere was what played a dirty trick on them. Although the diameter of Titan is only 5 000 kilometres, that is, two and a half times smaller than that of the earth, the thickness of its atmospheric envelope is ten times the thickness of the earth's atmosphere, and methane is concentrated mainly in its upper layer. This "methane mask" distorted the picture and created a wrong idea about the gas composition of Titan's atmosphere as a whole.

## Common Sense Defied

So far we have discussed cases where the clear visual impression should not necessarily be taken for granted. "Do not believe your own eyes" means "check what you see over and over again". But there is another side to the question of how the "obvious" and the "clear" should be treated in science. Is the quality of something being visually clear an indispensable condition for a conclusive scientific statement? In other words, if a scientific proposition reflects the real state of affairs correctly, does this mean that we will definitely be able to imagine everything associated with this reality graphically and in such a way that it will be accepted by our common sense?

Let us first establish what "common sense" is. We have already mentioned the fact that the actual universe is much more varied than our scientific conceptions of it. No matter what progress we should make in our research, some gaps are bound to remain. All scientific theories, as said above, have clearly defined limits of applicability. Generally we do not know just where these limits are, and so it is only logical that attempts to apply existing notions in areas extending beyond them inevitably lead to erroneous conclusions. However, until refuted by new knowledge, these conclusions will be regarded as correct and true. That is how *misconceptions* are born. The "common sense" of a given historical epoch is knowledge plus misconceptions accepted as knowledge.

Paradoxical though it may seem, besides being inevitable, misconceptions are also indispensable. It is difficult to apply knowledge in which gaps are clearly evident because such knowledge fails to give a whole picture of phenomena under study. The gaps are temporarily bridged by misconceptions.

In other words, a misconception is something like "temporary knowledge", or more exactly, "ignorance taken for knowledge".

It goes without saying that it is important to distinguish between common sense as we know it in our everyday life, that is, common sense which is a generalization of our practical experience, and that based on scientific knowledge.

What determined common sense at a time the first system of the universe, the system of Aristotle-Ptolemy, was formulated? What did science have at its disposal to rely upon? Just the results of observations of immovable stars, of the daily motion of the celestial sphere and the yearly loops travelled by the planets. That was knowledge. But it was insufficient to explain the reasons for what was being observed and to draw a logical and conclusive picture of the universe.

The result was that the motion of celestial bodies observed from the earth was wrongly taken for the absolute truth, giving rise to one of humanity's greatest and most persistent misconceptions — the postulate of the geocentricity of the universe.

Yet this misconception equipped science with a uniform and logical model of the universe, which not only explained the movement of celestial bodies but also made it possible to calculate future positions of the planets among the stars with precision that was quite adequate for those times.

We know today that the system of Aristotle-Ptolemy and the ratio of knowledge to misconception this system determined marked only one stage in the cognition of nature. The transition to the next stage required not only great effort on the part of mankind's finest minds, but also the overcoming of fierce resistance. We do not mean just the resistance of the church, which recognized the Aristotle-Ptolemy system as the only correct picture of the universe, but resistance stemming from the common sense of that epoch, the common sense which accepts traditional misconceptions as knowledge and regards new knowledge as misconceptions.[1]

But finally new knowledge was recognized as such and accepted and the Copernican teaching replaced the astronomy of Aristotle and Ptolemy.

The old misconception of geocentrism had to be discarded. But the new system too contained a number of misconceptions. Its author believed that all the planets revolved around the sun along strictly circumferential orbits with constant angular velocities, and that the universe stretched as far as the sphere of fixed stars.

The next step was Kepler's discovery of the laws of revolution of the planets around the sun. Kepler showed that the planets moved along elliptical trajectories with varying velocities But in his search for the causes of planetary motion Kepler proceeded from the erroneous assumption that for a body to keep in uniform motion in a straight line it was necessary that it should have a force constantly impressed on it.

And he was looking for such a force in the solar system, a force that was ever "pushing" the planets on and not letting them stop.

But soon came the end of that misconception as well — Galileo discovered inertia and Newton, the fundamental laws of motion and the law of universal gravitation. Those discoveries brought about the final elucidation of the laws of the solar system and refuted the concept of the sphere of fixed stars.

Classical physics arrived at the conclusion that all the bodies of the universe existed and moved in infinite space.

At the same time even Newtonian classical physics brought forth a new misconception — the firm belief that all natural phenomena without exception could be reduced to purely mechanical processes. This is to say nothing about "small" misconceptions, such as "absolute space" and "absolute time".

From the point of view of classical physics all questions concerned with the universe were verified finally and irrefutably, and so were, for that matter, almost all other questions. But the newly-achieved clarity was likewise deceptive, and the actual state of affairs turned out to be much more complicated than was believed in Newton's times.

Einstein's discovery of the theory of relativity at the break of the century completely undermined the then commonly accepted Newtonian postulates of space and of the geometrical properties of the universe. One of Einstein's major contributions was his establishment of the profound connection between the properties of matter and the geometry of space.

The new transformation of the "common sense" of science was very aptly expressed in verse:

> Our world was clothed in mystery black as night
> Till Isaac Newton said: "Let there be light!"
> But Satan was not long to fret and frown,
> Soon Einstein came to put things upside down.

Incidentally, the first and second couplets were written by different authors with an interval of about 200 years.

The poem, of course, states only one fact correctly — the classical postulates of space had to be abandoned. But it did not mean that the theory of relativity was to take science back to pre-Newtonian, Aristotlean times. It was only a new landmark on the path to an even more profound understanding of the universe.

Even today the transformation of the "common sense" of science continues and will continue in the future. For our modern knowledge of the universe is likewise far from being the absolute truth.

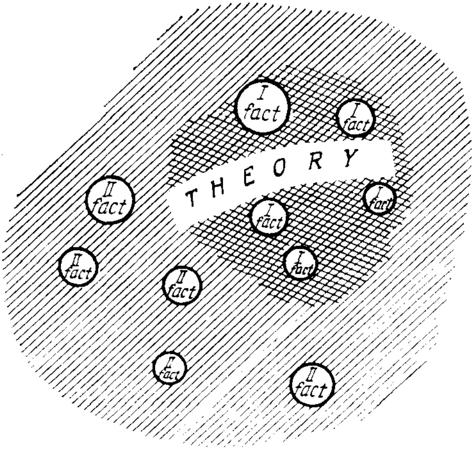
Thus, "common sense" in science is a relative notion, depending on the level of knowledge of the given epoch. That is why in their effort to achieve a higher level in the cognition of the universe, scientists inevitably come to grips with the routine of accepted notions and "common sense".

As for graphic clarity, the greater the advance of science, especially of physics and astronomy, the less we can rely on our judgement of what we can visualize. Perhaps, this is not what we like doing most, perhaps it is even irritating, but there is no getting away from it.

New physics and astronomy are a strange world where it is very difficult or even impossible to have a clear picture of many things. Following the tortuous path of science with its setbacks and its incredible discoveries that are not easily accepted by our common sense, we must not forget that common sense is never without a proportion of misconception.

## From Theory to Theory

As mentioned above, discovery of fundamentally new facts inexplicable within the bounds of existing theory leads to elaboration of a more general theory which will also "incorporate" the old one.



Evolution of knowledge from special to general theory

As Soviet cosmologist A. Zelmanov notes, if it is found that a group of laws can be deduced from more general laws in the process of cognition, this is not at all to mean that the former can wholly be reduced to the latter. Both have their specifics. The relation between special and general theories is much more complex.

Let us consider two physical theories, one special and the other general. The area of applicability of the former will lie within the area of applicability of the latter. The two theories have different equations. The point is not only that the equations of the general theory are more precise. The physical values making up the equations of the two theories are different. This is so because some values are common for both the special and general theories but some are not.

New values are included in the more general scientific theory as new concepts are established. The transition from a special theory to the general reveals that the *concepts* of the special theory (concepts and not equations) are only an *approximation* to reality, while the new concepts of the general theory are more precise, hence closer to it.

The transition from special to general theory is accompanied by what could be termed a breakdown of concepts. In this is constituted the qualitative difference between special and general theories.

How is it possible then for one of them to be a special case of the other following from it? The equations of the more general theory contain one universal constant more than the special. At present science knows three such constants:

the gravitational constant, the quantum of action (Planck's constant) and the velocity of light (the reciprocal is usually used).

For example, the equations of Newtonian mechanics contain no universal constants but the equations of quantum mechanics of which Newtonian mechanics is a special case contain Planck's constant.

In order to infer a special theory from the general it is necessary to transform the equations accordingly and approach the limit where the value of the "extra" constant is close to zero. The equations obtained as a result of such transformation will not be equivalent to the initial; they will be qualitatively different, containing different values and having different meanings.

For this reason if we have only the equations of a special theory at our disposal we will not be able to carry out a reverse operation, i.e., restore the equations of the general theory on the basis of the special, since the latter's expression would give us no hint as to what the equations of the general theory should be. In order to be able to do that we must resort to notions of a higher order, perhaps to philosophy. Naturally, this argument should not be understood literally; it is impossible to work out equations or obtain other concrete physical results on the basis of purely philosophic reasoning. But philosophic principles help to outline more promising ways of scientific progress and make a correct choice between possible versions of new theories.

In historical terms transition from a special to general theory signifies a revolution accomplished by means of fundamentally new, sometimes "irrational" ideas and concepts.

Take Newton's theory of gravitation and the general theory of relativity. The first is valid for Euclidean space and time which is independent of it, the second, for the space-time continuum characterized by non-Euclidean properties. The acceptance of these fundamentally new conceptions marked a revolutionary shift in the theory of gravitation.

In this way, special and general theories are qualitatively different. And it would be more correct to term special theory not an individual but a limiting case of general theory.

## Chapter 2

# The Solar Family

### The Earth and the Pendulum

The history of science abounds in problems that took the finest minds centuries to solve. Clarity was achieved at the price of enormous effort and long, selfless struggle against false conceptions. In many cases similar results were obtained later by far less complex means or were simply inferred from new discoveries.

One such problem was the problem of the earth's rotation on its axis. The fact that people inhabit a rotating planet — something that is plain to us living in the 20th century — had appeared impossible to prove for a very long time.

In general, acceleration due to rotation (the Coriolis acceleration) can be discovered in a rotating system. It is this acceleration that erodes the right banks of rivers in the northern hemisphere and the left banks in the southern.

But the Coriolis acceleration manifests itself only in a body in motion and besides, it is still only indirect proof of our planet's rotation.

Phenomena that provide proof of the very fact of the earth's rotation are much more convincing than those proving acceleration. It would seem that the visible daily movement of the sun in the sky and the day-to-night changes could be taken for indisputable proof of the rotation of the earth. But the difficulty is that we would observe the same picture if the earth were stationary and the heavenly bodies, the sun included, travelled around it.

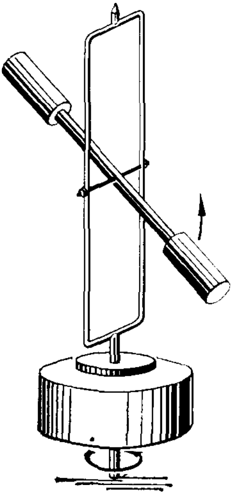
It was possible to judge about the rotation of other celestial bodies on the basis of direct observations. For example, the rotation of the sun could be seen from sunspot displacements, and of Mars, from the changes in the surface feature patterns observable from the earth. As to our own planet, it could not be observed from some other place.

Foucault's swinging pendulum experiment convincingly proved the earth's rotation. The pendulum — a load suspended by a thread — is one of the simplest and most remarkable instruments. The physical basis of the experiment is as follows. The forces acting on the swinging pendulum, the force of gravitation and the force stretching the thread, lie in one plane, the swinging pendulum plane. Therefore if a freely suspended pendulum is put into motion, it will swing in one and the same plane all the time. This property is defined in physics as follows: "The plane of the swinging pendulum does not change its position in space".

The way the earth's rotation is proved by means of a swinging pendulum is well known and we shall not go into it here. But it must be mentioned that this experiment has one significant drawback: it takes considerable time to establish the turn of the plane of the swinging pendulum due to the earth's rotation with sufficient reliability.

At the beginning of the 1950s the Soviet engineer Poshekhonov invented an original instrument to prove the daily rotation of our planet. Essentially it is also a pendulum, but not of the usual kind, and the proof itself is based on an entirely new principle.

The pendulum consists of a vertical frame mounted on a base in such a way that it can rotate on a vertical axis. A freely revolving rod with loads on its ends is attached in the middle to a horizontal axis fixed between the sides of the frame.



Pshekhonov's pendulum

The work of the instrument is based on the law of conservation of moment of momentum.

Moment of momentum $N$ is the product of the mass $m$ of the given body, its linear speed $v$ and the body's distance $R$ from the axis of rotation. But linear speed is the product of $R$ and the angular velocity $\omega$ ($v = R\omega$).

Thus, $N = m\omega R^2$ where $m$ is a constant value.

Let us assume that the radius $R$ is reduced, i.e., the body moves towards the axis of rotation. Since $m$ is a constant, for the product $\omega R^2$ to remain unchanged, the value of $\omega$ must be enlarged.

In other words, angular velocity increases as the revolving masses approach the axis of rotation.

Let us examine the motions of a figure skater. Flinging his arms out or bringing them to his chest he regulates his speed of rotation. The parachutist on a delayed drop employs the same method, as does the cosmonaut freely floating in his cabin or in open space under conditions of weightlessness. But back to our pendulum. Let us secure it on a stationary base and let the central rod revolve round the horizontal axis. It will continue in motion until friction in the bearings stops it. Such is the case with a stationary base.

Now let the base rotate uniformly around the vertical axis, in other words, let us imagine the pendulum to be in the centre of a rotating base. We will have an entirely different picture.

At the moment the rod is in the horizontal position, that is, the loads are situated far from the vertical axis, the pendulum revolves together with the base. But the moment the rod assumes the vertical position and the loads on its ends are situated on the axis of rotation of the base, the angular velocity of the frame's rotation in relation to the vertical axis will increase. The frame together with the rod will make a "jerk" since the speed of its rotation will exceed that of the rotation of the base.

Thus, when the pendulum is on a rotating base, a gradual turn will be observed in the plane of rotation of the rod. On the strength of this principle it will be easy to judge about the rotation of the base even without directly observing it.

And this means in turn that Poshekhonov's pendulum can be used to prove the earth's rotation convincingly. The displacement effect in this case will be achieved much sooner than in Foucault's pendulum.

Poshekhonov's pendulum was set up in the foyer of the Moscow Planetarium some ten years ago and has been working faultlessly ever since, demonstrating the principles discussed above exactly as designed.

It would seem that the best way to study the earth would be to explore its every corner, to penetrate deep into its interior and to study all the phenomena taking place there and on the surface. That is exactly what scientists do.

In many cases, however, the solution of terrestrial problems requires that the scientists should "break away" from our planet and tackle these problems from space. There is really nothing surprising in that. An unwritten law in natural science says: in order to study an object, one must regard it not only by itself but also in the context of a much broader set of objects. In our particular case, observations from space provide convincing visual proof of our planet's rotation. Let us examine the movement of the artificial earth satellites.

A satellite moving along a circumterrestrial orbit is actually influenced only by the force of the earth's gravitation, lying in the plane of this orbit (here we shall not consider deviations due to the fact that the earth is not an ideal sphere and other such subtle points). Owing to this fact the plane of the satellite's orbit does not change its position in relation to the stars within short spans of time. Were not the globe rotating around its axis, the satellite would pass over the same points on its surface with every turn. However, since the earth is rotating in the west-east direction, the satellite's trajectory, that is, the projection of its motion on the earth's surface is continuously shifting to the west.

It is known that a satellite moving at an altitude of 200 to 300 kilometres makes a full revolution around the earth within 90 minutes. It is easy to calculate that within this time the globe makes a turn of 22.5°. Since the length of the equator is about 40 000 km, the turn of 22.5° corresponds roughly to 2 500 km. It follows that each time the satellite makes a revolution around the earth, it crosses the equator 2 500 kilometres west of the point of its previous crossing. In approximately 24 hours after the launching, having made 16 revolutions round the earth, the satellite will pass above the region of the launching.

It will be recalled that the Soviet spaceships *Soyuz 6*, *Soyuz 7* and *Soyuz 8* on the group flight of 1969 had been launched at a space of 24 hours between each.

## The Star-Filled Sky Above

Why are the stars invisible in the daytime? For the air is as transparent then as it is at night. The answer is, because in the daytime the atmosphere disperses solar light.

Imagine yourself in a well-lit room in the evening. If you look out of the window, you will see the street lights well enough, but you will see practically nothing else. Objects on which no light is falling or which do not give out any light of their own remain invisible. But the minute you turn the light off in the room, the window glass ceases to be an obstacle to your vision.

Something in the same nature occurs when we observe the sky. In the daytime the atmosphere above is well-lit and we can see the sun, but the light of distant stars cannot come through. When the sun sinks below the horizon and solar light (and together with it, the light dispersed by the air) is "switched off", the atmosphere becomes "transparent" and we can see the stars.

The picture is different in outer space. As a spaceship gains altitude, the dense layers of the atmosphere are left below and the sky is gradually darkening.

At an altitude of about 200-300 km, where the paths of manned ships usually lie, the sky is absolutely black. It is black even when the sun is on its visible side.

Commenting on his impressions of space, the world's first spaceman, Yuri Gagarin, wrote: "The sky is perfectly black. Against this background the stars look brighter and are outlined more sharply."

Even so, not all the stars but only the brightest ones can be seen from on board a spaceship. The dazzling sun light and the light of the earth obscure vision.

*Seen from the earth, all the stars are sparkling.* They seem to fade, then light up again, all the time changing in colour. The lower a star is to the horizon, the stronger its scintillation.

Scintillation is also expressed by the presence of the atmosphere. Before reaching our eye the light emitted by a star passes through the atmosphere which consists of masses of cold and warm air. The density of the air in an area of the atmosphere depends on its temperature. Passing from one area to another, light beams are refracted and the direction of their dispersal is changed with the result that they become concentrated over some areas of earth's surface and dispersed over others Since the air masses are constantly moving, these areas change their position too, and the observer on the earth sees the stars changing in brightness. But different colour beams are not refracted similarly and intensification or fading of colours does not occur simultaneously.

Other more complex optical factors may also be responsible for the stars' scintillation.

The presence of warm and cold layers in the air and the fact that the air masses are moving fast tell on the quality of telescopic pictures as well.

What regions of the earth provide optimal conditions for astronomic observations? Are they the best in the mountains, or on the plain, on a sea coast or deep in the mainland, in the forest or in the desert? And in general what is better for the astronomers, ten cloudless nights a month, or only one clear night when the air is ideally transparent and calm?

These and many other questions have to be answered before a site for the construction of an observatory with a big telescope is selected. And the answers are provided by workers in astroclimatology, a special department of science.

One of the world's biggest telescopes with a mirror six metres in diameter — one metre bigger than the mirror of the famous Palomar telescope in the United States, was commissioned in the Soviet Union some ten years ago.

What does one metre mean for astronomers? The limits of the observable area of the universe extend by 20 per cent.

The building of the new telescope was preceded by several years of astroclimatological research *conducted by the staff of the Pulkovo Observatory* of the USSR Academy of Sciences. Conditions in different parts of the Soviet Union were studied, and particularly in the Kuban steppes, the Caucasus, Georgia, Armenia, the Pamir and Tien Shan mountains, on Lake Issyk-Kul and in the Ussuri territory. The new observatory, housing the six-metre giant, was built in the Stavropol region in the Northern Caucasus.

It must be said, though, that the conditions are even better in Central Asia and the Pamir mountains. But construction there would involve enormous technical difficulties and cost much more. This is not to mention the fact that these regions are too far away from major scientific centres.

It goes without saying that an observatory situated in outer space, beyond the cloak of the dense layers of the atmosphere, would really be perfect. As a matter of fact, the stars there are not twinkling; they are giving out a cold even light.

In space the familiar constellations look exactly the same as when they are observed from the earth. The stars are tremendous distances away from us and being a few hundred kilometres closer to them does not change anything in the way we perceive their respective positions. Even observations from Pluto would reveal nothing new in their appearance.

In principle, it is possible during one revolution around the earth, to see all the constellations on our sky from on board a space vehicle moving along a circumterrestrial orbit. Observations of stars in outer space have a dual, astronomic and navigational interest. First, it is very important to observe star light unchanged by the atmosphere, and second, nothing can replace navigation by stars in the event of disruption of the spaceship's radiocommunications with earth. By watching the previously selected "orientation" stars it will be possible not only to correct the course but also establish the ship's position in space.

For years have astronomers dreamed of future observatories on the moon, believing that the complete absence of an atmosphere should provide ideal conditions for optical observations both during the lunar day and lunar night.

With this purpose in mind special studies were carried out by means of the Soviet *Lunokhod 2* unmanned space laboratory. It was equipped with a photometer specially designed and built at the Crimean astrophysical observatory of the USSR Academy of Sciences, and mounted in such a way that its optical axis was always pointing to the zenith of the moon's sky.

The measurements yielded unexpected results: the luminescence of the lunar sky, both in visible, and especially, in ultraviolet radiation was much more intense than was expected. As further studies showed, this could be due to dust particles moving in lunar space. It was suggested that the moon is enveloped in a cloud of rarefied dust particles formed as a result of meteoritic and micrometeoritic bombardment of its surface. Maintained at some distance by electrostatic forces, these particles disperse not only solar light but also the light coming from the earth. And our planet in the lunar sky is a luminary 40 times as bright as the full moon in the earth's sky.

The dust cloud around the moon may impair observations from future observatories on the moon.

## What is New on the Tunguska Meteorite

The mysterious event referred to as the Tunguska meteorite took place in Siberia in 1908 and has attracted much attention ever since.

At dawn on June 30, 1908, the primeval tranquillity of the Siberian taiga was shattered as a dazzling object flashed across the sky with tremendous speed and, leaving a trail of thick black smoke behind, disappeared below the horizon. A moment later a great column of fire soared into the sky at the Vanovar trading station on the river Podkamennaya Tunguska and it was clearly observed at a distance of up to 450 kilometres. Then the view was obscured by a huge cloud of smoke. All this was accompanied by deafening explosions which could be heard at a distance of 100 kilometres. The ground shuddered over a vast area just as during a powerful earthquake, buildings shook, window-panes burst and every suspended object was swinging. The quakes were registered by many of the world's seismic stations, and the air blast had travelled around the earth several times.

The first expedition to the site of the Tunguska catastrophe was organized only after the revolution, in 1927, by the USSR Academy of Sciences. Another two expeditions went there between 1928 and 1930, and aerial photography, though incomplete, was carried out in 1938.

Further studies were interrupted by the Second World War and the next Tunguska expedition took place as late as 1958. During the last few years, however, the site has been visited by many well-equipped expeditions including those organized by the USSR Academy of Sciences.

Some mysterious facts were discovered even during the initial investigations. For instance, not a single crater, such that usually form from the impact of space objects falling to the surface of the earth and not a single splinter of rock was found. The forest had been brought down over an area of scores of square kilometres and the trunks of the fallen trees were all pointing in the direction of the centre of the explosion. But it was precisely in the centre, where it would be logical to expect the destruction to be the greatest, that the trees remained upright. Their tops and almost all the branches, however, had been broken off in such a way as to suggest that they had been hit by an air blast from above.

This gave reason to suppose that the Tunguska object exploded in the air, at a considerable altitude above the earth. Furthermore, everything pointed to it being an explosion occurring momentarily, over a few hundredths of a second, otherwise the even, radial array of the tree trunks on the ground would have been impossible. Several hypotheses concerning the nature of the mysterious object were advanced, some of them quite exotic. One theory suggested that it was a spaceship belonging to an extraterrestrial civilization which suffered a breakdown causing a nuclear explosion over the Siberian taiga.

All speculations (we mean scientific hypotheses), however, raised serious doubts and not one of them could wholly be accepted.

The history of the Tunguska meteorite is a graphic illustration of what happens in every case when a natural event cannot satisfactorily be explained for a long time. As a rule, when scientists seek such an explanation they try to check it against every new fundamental discovery in their respective field.

Thus when anti-particles were discovered and the idea of anti-matter was developed in elementary particles physics, it was suggested that the Tunguska object was a small lump of anti-matter which had for billions of years been carried about in space until it collided with our planet. Contact between matter and anti-matter resulted in the annihilation of both and their conversion into electromagnetic radiation accompanied by the release of a tremendous amount of energy. That energy, according to the authors of the hypothesis, explained the destruction caused by the Tunguska explosion.

The suggestion about the "anti-nature" of the Tungska object did not become very popular. It was difficult to explain, among other things, how a splinter of anti-matter could have survived for long while in constant motion in space. It would have inevitably collided with the numerous particles of interstellar and interplanetary media and would have been annihilated many times over.

Another attempt to explain the Tunguska meteorite was associated with one of the greatest physical discoveries of our time: the development of quantum generators or lasers. It was suggested that all events that occurred in the Siberian taiga in 1908 were caused by a powerful space laser beam of an unknown origin which had "slashed" our planet. That theory sounded so fantastic that no one really took it seriously.

One more attempt to explain the explosion on the basis of a new physical idea was made in the last few years. This time the point of departure was the black hole hypothesis which has been enthusiastically developed by physicists and astrophysicists. A black hole is a body whose matter has contracted to such an extent that it has been "locked up" by its own gravitational forces. This object captures any matter from the surrounding medium and not a single particle nor any kind of radiation can break out of it (more on black holes in Chapter 3). Accordingly, workers at Texas University suggested that the Tunguska meteorite was actually a small black hole which broke into the earth's atmosphere at colossal speed.

More accurate calculations, however, carried out by physicists in many countries showed that events which should have been observed if a black hole had collided with our planet could not have anything in common with what really happened during the Tunguska catastrophe.

The search continued. Interesting experiments were carried out at the Institute of Physics of the Earth. A model of the site of the catastrophe where numerous wires represented trees in the taiga was placed in a special chamber. Small gunpowder charges were exploded over different spots and at different altitudes, each of them being brought to the planned spot with different velocities and at different angles. In each of the experiments the pattern of the fallen "trees" was different. In some cases it corresponded to that found on the site of the catastrophe.

It was established that the Tunguska object was moving at a speed of 30 to 50 kilometres per second and the explosion occurred at a height of 5 to 15 kilometres. The power of the explosion was equal to an explosion of 20 to 40 megatons of TNT. The destruction was apparently caused by the blast from the explosion above the earth's surface and by another one which bounced off from the surface.

An interesting hypothesis was advanced by Academician Vasili Fesenkov, the Soviet well-known astronomer. His idea was that in the summer of 1908 the earth collided with the ice nucleus of a small comet. According to calculations carried out by another Soviet astronomer, K. P. Stanyukovich, as the comet entered the earth's atmosphere at supersonic speed, its low-melting ice was first evaporating at a comparatively low rate. But when it reached the lower, dense layers of the atmosphere and when the mass of ice sufficiently warmed up it instantly turned into a gas blob and evaporated in a powerful explosion.

Further calculations showed that this theory agreed well with all the events observed during the Tunguska explosion and afterwards. But in order to accept this hypothesis in preference to all the others additional data were required, especially since no comets were registered in the region of the sun in 1908. A small comet could, of course, have gone unnoticed, but still independent confirmation of the comet theory was essential. Such confirmation was finally obtained.

Astronomers have long since noticed that after the passage of a bolide (a fire-ball flashing across the sky and sputtering fire), resulting from a fairly large space object entering the earth's atmosphere, no meteorites fall over the region of this spectacular event. This observation was confirmed recently by Czechoslovak and American astronomers who systematically photographed bolides by means of special "meteorite nets".

It is logical to suppose, therefore, that most of the space objects getting into the earth's atmosphere do not reach its surface (although sufficiently large stone or iron meteorites could be expected to hit the ground) This fact alone suggests that the object which caused the Tunguska explosion and objects observed as bolides should have a similar physical nature.

Not long ago a Moscow astronomer, V. A. Bronshten, comparing data on 33 bolides with those on the Tunguska meteorite arrived at the conclusion that the Tunguska object and most of the bolides are physically similar. In other words, all these objects have small density and are easily destroyed when they reach the atmosphere.

Yet another theory was recently proposed by a prominent Soviet scientist, Academician Georgi Petrov. This hypothesis elaborates on the idea of an ice comet. According to the scientist, it was a huge ice ball, that is, an object with a very loose nucleus consisting of ice crystals and having a mass of something like 100 000 tons and a diameter of up to 300 metres; its density was only a fraction of the density of water.

On entering the earth's atmosphere at a speed of more than 100 times the speed of sound, the ball of ice warmed up rapidly and began to evaporate at a fast rate. A few kilometres from the ground the remains of the ball and the gas masses around it immediately expanded forming a powerful air blast. That was what brought the trees down over an area of scores of square kilometres and explained their radial pattern.

This hypothesis offers a good explanation of the nature of the Tunguska explosion and of the fact that no craters or splinters were found in the area. All the same there is no consensus among scientists on the explosion of 1908 and much is yet to be learned about it

One thing is definite: the Tunguska meteorite is a unique event and the unfading interest in it is totally justified. It may well be expected that the further search will result in the discovery of hitherto unknown facts about space and about our own planet.

## Astronautics Checks out Astronomy

Can scientific research yield authentic information if the object under study is situated some considerable distance away? Can such research give a true picture of the external world?

These questions directly concern astronomy. Since space objects are so remote from the earth astronomers were not able until very recently to study them directly. The development of rocket engineering and the successful space exploration over the last few years has provided them with such a possibility. "Space-bound" astronomy has come into being. Space probes take measuring instruments and television cameras to the regions of the closest space objects and even manage to land equipment on their surface.

It has become perfectly feasible to compare the knowledge painstakingly pieced together by generations of astronomers with the latest data about the solar system. What does such comparison reveal?

This question has been answered by the well-known Soviet astronomer Iosif Shklovsky, Corresponding member of the USSR Academy of Sciences, in an imaginative, perhaps even paradoxical way:

"The greatest achievement in the exploration of the solar system by means of space probes is the fact that no great discoveries have been made in this field. It has not been found that 'everything is not as had been expected'. The fundamental scheme of the processes occurring in the planetary family of the sun drawn by earth-bound astronomers has been convincingly confirmed..."

This conclusion is of the utmost importance. Despite the great distances separating astronomers from the objects of their observations and despite the difficulties this involves, astronomic studies yield authentic information about the universe.

Understandably, the role of the new, cosmic astronomy goes beyond mere confirmation of previous knowledge or it would probably not be worth developing it at all. In many cases the new method of space study is much more effective than the traditional, enabling scientists to obtain fundamentally new information, clarify important points about space events and find answers to many riddles that have intrigued them for a long time.

The properties of lunar rock, for instance, had been the subject of a heated debate before space probes were sent to the moon. One theory was that owing to meteoritic bombardment over billions of years, the surface of the moon had to be reduced to a thick layer of the finest dust which could suck in a spaceship attempting to land on it. Researchers at the Radiophysical Institute in Gorky undertook to verify this hypothesis.

Their studies of thermal radio radiation coming from the moon showed that there was no thick layer of dust there, but that its surface material was firm enough and in mechanical properties resembled wet sand. Not that it was really wet, it simply had some common characteristics with wet sand.

This conclusion drawn by earth-bound astronomers was confirmed by numerous space probes that visited the moon, by the Soviet *Lunokhods* and by the American expeditions.

Now let us try to establish why astronomic, and especially radioastronomic studies carried out in terrestrial conditions produce results that agree with the real state of affairs.

First we must learn about the principles which distinguish radioastronomic from optical observations. The main principle is that not the space objects proper but their radiations—electromagnetic and corpuscular—are studied. Since the properties of these radiations depend on the properties of their sources, they contain information about space objects and about the diverse physical processes occurring in the universe.

Thus radioastronomic research consists in the observation and registration of the various radiations coming from space, and in subsequent processing of the information they carry. Essentially these methods are similar to those used by physicists in terrestrial laboratories, and some of them lend themselves to exhaustive experimental verification.

The French philosopher, August Comte, declared almost a century ago that it would never be possible to learn about the chemical composition of the stars. But like many other pessimistic predictions, Comte's assertion was soon disproved. The method of spectral analysis of white light developed by physicists and checked out in laboratories numerous times proved to be a reliable and effective method of determining the chemical composition of distant objects. Spectral studies enabled scientists also to determine the surface temperatures, physical states and magnetic properties of these objects and the speeds of their motion in space, and thus answer many long outstanding questions.

The same is true of other methods of astronomic studies. This means that cosmic astronomy cannot do without its earth-bound counterpart. There are many problems that can be solved only on the basis of optical and radioastronomic observations conducted simultaneously, on the basis of comparing data obtained by different methods. Only this makes it possible to understand the physical nature of some of the observations carried out from on board space orbiters. No further harmonious development of astronomy is conceivable without adequate facilities on earth.

## The Fate of a Hypothesis

Mars has two small moons, Phobos and Deimos. Deimos travels an orbit 23 thousand kilometres away from Mars and the orbit of Phobos is only nine thousand kilometres from that planet. It will be recalled that the distance between the earth and its moon is 385 thousand kilometres, or more than 40 times the distance between Phobos and Mars.

The history of study of Phobos and Deimos is rich in incredible events and fascinating riddles. Judge for yourself: the first mention of the fact that Mars has two satellites is to be found not in scientific records but in Jonathan Swift's famous *Gulliver's Travels* written in early 18th century.

You will remember that one day Gulliver found himself on the Flying Island of Laputa where astronomers told him about their discovery of two small satellites revolving about Mars.

But fiction aside, the Martian moons were actually discovered by A. Hall, the American astronomer, a century and a half after the publication of *Gulliver's Travels*, in 1877, during the great opposition of Mars. The discovery was made under extremely favourable atmospheric conditions, after days of strenuous observations exhausting the powers of the human eye and the instruments.

Today we can only guess about what prompted Swift to make his prediction. Definitely not telescopic observations. Most likely the writer assumed that the number of planetary satellites had to increase with distance from the sun. In Swift's times astronomers knew that Venus had no satellites, that the earth had one satellite, and that Jupiter had four (they were discovered by Galileo in 1610). A geometrical progression was thus self-evident and the number two seemed to fit the vacancy that corresponded to Mars.

But that was not all. Swift also gave some startlingly accurate measurements. According to him, the radius of the orbit of the Martian inner satellite equalled the planet's three diameters, and that of the outer satellite, five diameters. Three diameters come to about 20 thousand kilometres. The orbit of Deimos is indeed situated approximately at this distance from Mars. True, Deimos is the outer not inner satellite, as Swift thought, but still the coincidence is impressive. We must, of course, accept it as a coincidence...

The next time the Martian moons became the subject of scientific interest was in the latter half of this century. Comparing the results of observations carried out at different times, astronomers arrived at the conclusion that Phobos, the inner moon of Mars, was affected by a braking force, owing to which it was gradually drawing closer to the planet. That looked mysterious as no rule of celestial mechanics could explain it. The only thing which could be considered was that braking was due to the aerodynamic resistance of the Martian atmosphere. But calculations showed that being six thousand kilometres away from Phobos, this atmosphere could affect its motion in such a way only provided the mean density of matter on Phobos was small, or more accurately, unbelievably small.

It was then the extravagant idea that Phobos was hollow was put forward. Since we have no knowledge of natural processes which could lead to the formation of hollow objects in space, it was suggested that Phobos and probably Deimos as well were artificial satellites of Mars built by rational creatures millions of years ago, which had either populated Mars in those times or had arrived there from elsewhere in outer space.

Perhaps it would not be worth recalling this hypothesis now that the two satellites have been photographed by spacecraft from a small distance and there is not a shadow of doubt as to their natural origin, but for the fact that this incident is highly instructive.

There is science and science fiction. Where should the line dividing the one from the other be drawn in the theory of the Martian satellites? If braking indeed takes place in the movement of Phobos as claimed by observers, this really may mean that it is hollow. This is a justified scientific hypothesis based on astronomic data and mathematical calculations. Here we have a typical scheme of a scientific theory: "If this is so, then that must be so". The rest is science fiction.

It was clear from the start what would happen to the hypothesis concerning the Martian satellites. Like any other scientific theory it would either be confirmed or rejected. Much depended on the accuracy of further observations of the motion of Phobos. And accuracy was exactly what was doubtful since the observations were conducted at the outside limits of accuracy allowed by the instruments. It turned out that the doubts were well founded.

When unmanned space stations were placed at the disposal of the astronomers, the picture became perfectly clear. The photographs of Phobos and Deimos made in space revealed the outlines of two huge, irregularly shaped hunks of rock definitely of a natural origin.

A comparison of the results of terrestrial observations with those returned by space stations showed that the Martian moons are small space objects, the size of Phobos being 27 by 21 and of Deimos 15 by 12 kilometres. They are moving along almost circular orbits situated in the plane of the Martian equator and in the direction of the planet's daily rotation. Deimos completes one full revolution in 30 hours 18 minutes and

Phobos in seven hours 39 minutes. Since the duration of the Martian day and night is a little over 24 and a half hours it is easy to see that Phobos travels its orbit at a considerably higher speed than Mars rotates on its axis. An observer on the surface of Mars would be able to see that the semimajor axes of the two moons always point to the centre of Mars. (Recall that the earth's moon revolves around the planet in the same manner and we always see only one of its sides.)

The flight of *Viking 1*, the American unmanned space station, provided scientists with the first ever opportunity to evaluate the mass of Phobos. When the station's orbiter was passing Phobos at a distance of 100 kilometres, the American scientists were able to determine the perturbation of the orbiter's trajectory caused by the attraction of this Martian moon. After that it was easy for them to calculate the mass of Phobos, and since its size was known, it was also possible to calculate its mean density. It is close to 2 g/cm$^3$. This is nothing out of the ordinary and is roughly the same as the density of many stone meteorites. The hypothesis about the hollowness of Phobos and Deimos had to be discarded. Apparently its weak point were faulty original data on the motion of Phobos.

Gravity on the surface of Phobos was then determined on the basis of data concerning its mass. It is two-thousandths of the earth's gravity. It could probably be supposed that an astronaut on Phobos could break away from it at the slightest push. That is not quite so, however. Calculations have shown that escape velocity for Phobos is about 11.7 m/s, which is not little

Phobos, one of two Martian moons

at all. It can be developed on earth by a sportsman during a 2.5-metre high jump. And since the muscular effort required to perform an action is the same wherever it takes place, it is hardly possible for anyone to leave Phobos for good by pushing off its surface.

Of special interest are the photographs made at a distance of just a few tens of kilometres from Phobos and Deimos. They reveal a large number of craters that look much the same as the craters on the moon. The biggest one on Phobos is 10 kilometres in diameter.

At the time the density of Phobos was being debated, some astronomers who thought that it was very small, suggested this was due to meteoritic bombardment as a result of which the surface of Phobos became porous. This was a remarkable suggestion since it was made when it was still uncertain if even the craters on the earth's moon were of meteoritic or volcanic origin. The history of science knows quite a few instances where correct ideas were expressed on the basis of erroneous data (the small density of Phobos in this case).

Another outstanding detail visible on the photographs of Phobos are the almost parallel ridges which are up to several hundred metres wide and stretching for long distances. The origin of the ridges is obscure. It may be that they were produced by a powerful impact from a collision with a large meteorite which gave Phobos a good "shake-up" and caused its surface to crack, or that they were a result of perturbations caused by the gravitation of Mars. This latter view is supported by the fact that no such surface features were found on Deimos which is at a much greater distance from Mars, and as is known, gravitational action is reduced as distance increases.

As to the origin of Phobos and Deimos, it seems logical to suppose that they are asteroid-like objects captured in the gravitational field of Mars. It is even possible that they were formed before the planet itself. In any case further studies of the Martian moons will add to our knowledge of the laws governing the formation of the solar system.

## The Inevitable Craters

Ever since telescopic observations of the moon began scientific interest has centred on the ring-shaped mountains or craters covering a considerable area of the moon's visible side and some reaching 200 or even 300 kilometres in diameter.

Two theories explaining the origin of lunar craters—meteoritic and volcanic—had been heatedly debated for a long time. Until the moon was visited by spacecraft, data were lacking for any definite conclusion. The new information obtained in the recent history of space exploration furnishes convincing evidence supporting the impact origin of the overwhelming majority of lunar craters.

It has been found that the established number of meteoritic bodies travelling in interplanetary space at different periods agrees well with the incidence of craters in different areas of the moon's surface. It appears that the moon was subject to the most intense meteoritic bombardment during the first billion years of its existence. Subsequently, as the amount of meteoritic material in solar space decreased, the number of meteoritic impacts registered on the lunar surface decreased as well. This explains why the incidence of craters in the *maria* (seas) which were formed somewhat later than the highland areas on the moon is only about a thirtieth of that in the highlands.

At present meteoritic bombardment of the moon is not intense at all: one meteorite with a mass of about one kilogram falls to an area of 200 kilometres in radius once a month.

Micrometeoritic fallout is not intense either. But evidence of the action of micrometeorites on the whole surface of the moon over astronomical periods of time is still conspicuous: microscopic craters from the impacts of the tiniest particles of cosmic matter have been discovered in grains of rock samples returned to earth. Admixtures of meteoritic material were also found in the surface layer of lunar material in all the areas where samples were collected.

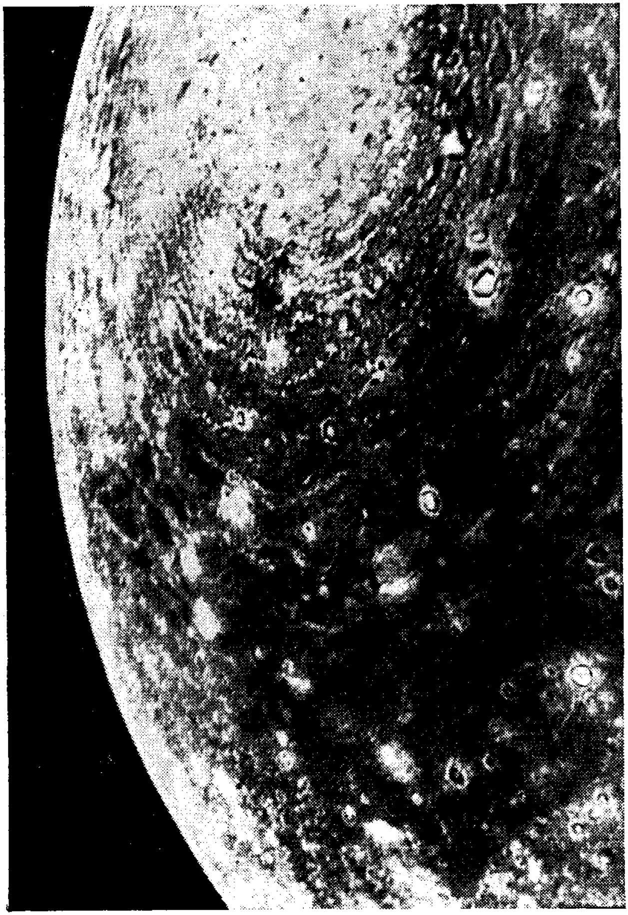
Strange as it may seem, the studies of Phobos furnish a convincing argument in support of the meteoritic origin of the craters on the moon.

As mentioned earlier, the surface of Phobos is simply pock-marked with craters, and there can be no doubt as to their impact origin: since this body is only 27 kilometres in length there is no room for any tectonic activity whatever. And this means that similar craters found on the moon must also be of meteoritic origin, especially since such craters have been discovered in recent years not only on Phobos but also on other bodies of the solar system and on Mars proper. The photographs taken from a Martian orbit reveal many areas of the planet dotted with craters resembling those on the moon. Most of them were formed in the same epoch as the craters in the lunar highlands, that is something like four billion years ago. Some craters have retained a good shape, while others have undergone considerable destruction or have almost completely been obliterated.

Numerous meteoritic craters have also been detected by space probes on Mercury, the closest planet to the sun. Craters cover almost the whole area of Mercury. The bigger of them are several dozen kilometres in diameter and the smaller (those that could be seen on television pictures transmitted from space), about 50 metres in diameter. Mercurian craters on the whole are smaller than those on the moon.

Some large craters have small ring-shaped formations inside presumably of a later origin. It seems that in the early stages the surface of Mercury was bombarded by objects of different sizes, including some very big ones, and that with the passage of time meteoritic bodies became smaller in size. This is confirmed by the fact that the younger craters in the lunar *maria* are far smaller than the older ones in the highlands. And it must also be noted that the surface features on Mercury were formed also in the same epoch as the lunar highlands (some four billion years ago).

Radar measurements also indicate the presence of crater systems on Venus. The surface of this planet cannot be observed with optical telescopes because it is completely shrouded in a cloud envelope. But radiowaves pass through the cloud and, reflected from the planet's surface, bring information on its surface features. Thus radio observations of an area of equatorial Venus have



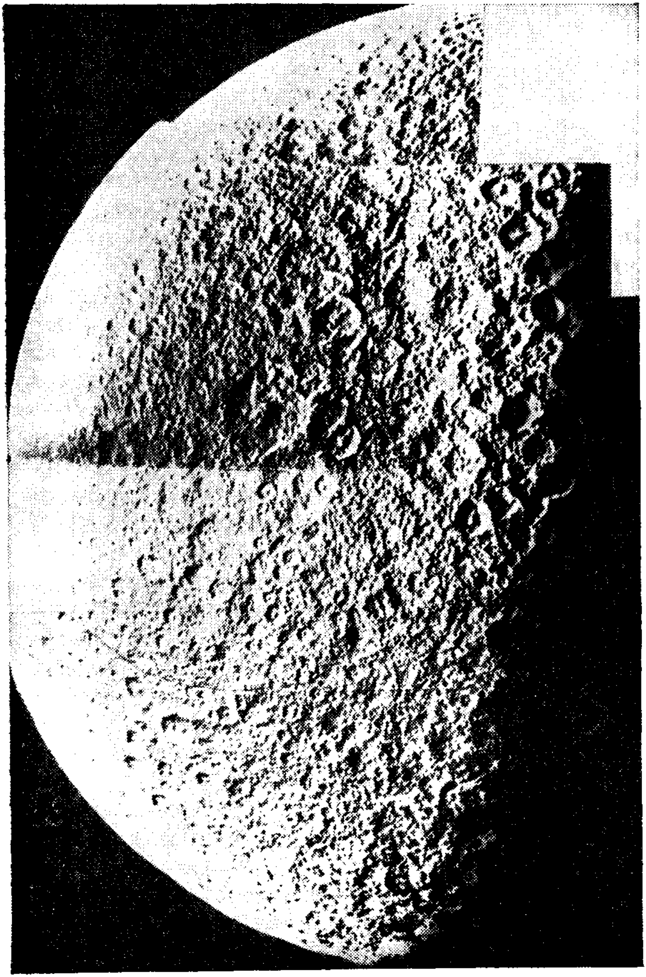
Jupiter's moon Callisto (Photograph by *Voyager 1*) revealed the presence of more than ten ring-shaped craters with diameters ranging between 35 and 150 kilometres. One crater, as large as 300 kilometres in diameter and one kilometre deep, has been named after Lise Meitner, the Austrian physicist who was one of the pioneers in radioactive research.

Unlike lunar and Mercurian craters, those on Venus look considerably flattened out.

An outstanding Venusian surface feature is a well-formed ring-shaped structure resembling a crater which is surrounded by a heavily destroyed double ridge measuring about 2 600 kilometres in diameter. Views on the origin of this structure vary.

Jupiter and Saturn are hydrogen-helium planets, but their numerous moons are of a terrestrial type. As recent studies have shown, they too had gone through a period of heavy bombardment in their early histories. Traces of numerous meteoritic impacts are clearly visible on the surface of two of the Galilean satellites of Jupiter—Ganymede and especially Callisto. Both these satellites are encased in a thick ice shell which explains the fact that the craters on them have a much lighter colouring than the ring structures on the earth's moon. The photograph of Ganymede made in space also shows the clear outlines of a dark basin with a diameter of over 3 000 kilometres. Quite likely it is the result of an encounter of Ganymede with a large body, such as an asteroid.

Some moons of Saturn also have meteoritic craters. On Mimas, for instance, on the side permanently facing Saturn there is a huge crater,



Rhea, a moon of Saturn (Photograph by *Voyager 1*)

130 kilometres in diameter, which is a third of the diameter of Mimas itself. According to calculations, if the impact which had caused the crater had been a little more powerful Mimas would have fallen apart. There are craters on the rest of its surface as well, and this makes it look like the earth's moon. They are smaller but rather deep.

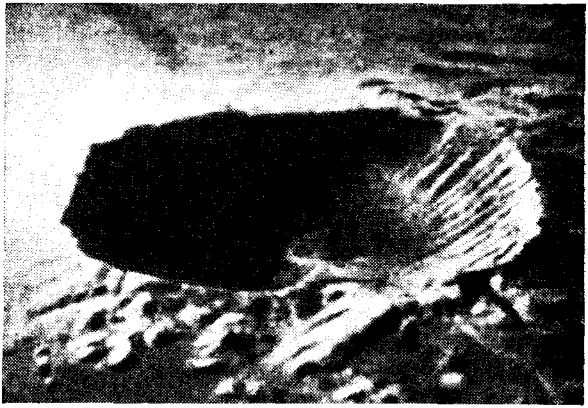
Large meteoritic craters have been discovered on Dione, another of Saturn's moons, the diameter of the largest of them being about 100 kilometres. Some of the craters have light-coloured radial lines extending from the centres, which are evidently traces of material ejected when Dione was hit by big meteorites. Another suggestion is that the lines are deposits of frost.

The biggest craters are visible on yet another moon of Saturn, Rhea. They are up to 300 kilometres in diameter and some of them have central apexes. Rhea also looks much like the earth's moon or Mercury.

The American *Voyager 2* space station, which visited the region of Saturn in August 1981, registered a crater between 400 and 500 kilometres in diameter on Tephys, one of the planet's more massive moons. Specialists believe it originated from a collision with a large body.

A crater 100 kilometres in diameter was also discovered on Saturn's moon Hyperion. This satellite is irregularly shaped and looks like a potato which, according to scientists, could also be the result of a major collision.

Thus impact craters are typical of both the terrestrial-type planets and the satellites of the giant planets. It is logical to ask here: what about such craters on our own planet?



The Arizona meteoritic crater

We do find some impact craters on our planet. One of them is in Arizona in the United States. Its diameter is about 1 200 metres and it is 174 metres deep. A group of such craters has been discovered on the island of Saaremaa in Estonia. The biggest of them is a water-filled reservoir 110 metres across.

But neither of these nor any other crater on the earth's surface can be compared with the craters, say, on the moon. Until recently it was believed that no craters such as discovered on other planets and satellites exist on the earth. This seemed strange because the earth evolved in the same epoch as its neighbours in space and big meteorites had to fall to its surface in some early period. One explanation is that over the billions of years of the earth's cosmic history the great cavities formed in places of its encounters with meteorites had been exposed to the combined action of a specific set of natural factors typical of this planet alone: rain, wind, seasonal changes in temperature, and various types of tectonic activity. This is not to mention the biosphere which also exerts a considerable transforming influence on the structure of the earth's crust.

On the other hand, structures like the giant ring-shaped meteoritic craters could come about in processes having nothing in common with falling space objects. Such processes include land subsidence, welling up of ice masses in regions of permafrost, and especially, volcanic eruptions.

Is there a way of distinguishing ancient meteoritic craters or astroblems, as they are termed, from volcanic structures? In principle there is. Volcanic activity is intimately connected with the structure of the earth's crust in the given region and is the result of the preceding evolution of this region. Meanwhile the location of impact craters is totally random as meteorites could hit any spot on the planet with equal probability. In other words, geological structures are wholly irrelevant to such craters.

Since considerable amounts of energy are released when large meteorites hit the earth, radial shearing of rock is to be observed around impact craters. Moreover, the crushing of rock in such regions upsets the distribution of the lines of magnetic force typical of the given locality. Another feature observed in the regions of meteoritic impacts are cone-shaped structures between a few centimetres and several metres high, the formation of which involves super-high pressures. Powerful impacts may result in the appearance of modifications of quartz characterized by unusual physical properties.

The following example will give the reader an idea of the stupendous scale of events caused by encounters with giant meteorites. The great explosion which accompanied the eruption of Bezymyanny volcano on the Kamchatka peninsula in the Soviet Union generated a pressure of three to five kilobars in its blast. This is maximum pressure which can build up during a geological process. The pressure created by collisions with giant meteorites is something like 250 kilobars and more.

Thus it is possible to distinguish between ancient astroblems and similarly shaped geological structures. This is of enormous practical significance, not to mention the purely scientific interest. If it is found that a given ring structure is of an impact and not volcanic origin, the possibility of mineral deposits in the area will be estimated differently.

One of the world's most fascinating astroblems was discovered in 1970 in the Popigay valley north of Krasnoyarsk in Siberia. It is 100 kilometres in diameter and 200 to 250 metres deep. Scientists believe that the meteorite responsible for it had to be several kilometres in diameter. The event happened about 40 million years ago. Curiously, though this astroblem is situated in the tundra, the vegetation inside it corresponds to forest tundra, and larches, a typical species of this zone, grow in abundance in it. Vegetation is practically nonexistent all around the astroblem and the tundra extends even farther to the south from it. This is probably to be explained by the fact that the Popigay astroblem is a depression, or that there is a warm subsurface flow in it.

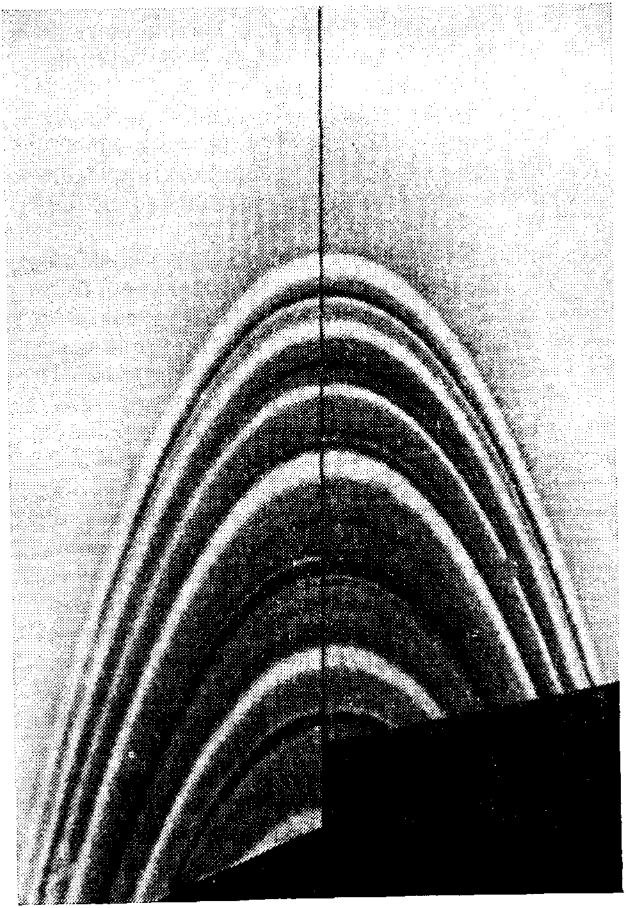
In all, several dozen old ring structures have been found in the Soviet Union, some 20 of them in Kazakhstan. Their meteoritic origin is called into question.

It can be said, nevertheless, that the earth and other planet-type bodies of the solar system were subject to heavy meteoritic bombardment at some early stage of their history. This is additional proof of their common evolution in a single process. Another conclusion of considerable importance to the study of the evolution of the solar system is that there was a period in its history when interplanetary space was full of large meteoritic bodies.

## Rings of Giant Planets

In its striking appearance Saturn stands out among all the other planets in the solar system. What makes it different is its beautiful belt of rings consisting of myriads of ice particles and lumps of ice up to several tens of metres thick, all revolving around the main body of the planet.

For a long time the rings of Saturn were considered to be unique in the planetary family. In 1976, however, terrestrial observations revealed Uranus, the seventh planet, also to have several rings. Some time later *Voyager 1* registered a faint ring around Jupiter as well. This ring consists of particles ranging between a micrometre and reveral metres in diameter.



Rings of Saturn (Photograph by *Voyager 1*)

Years of observations had led astronomers to believe that Saturn had four rings. They were designated by the capital letters A, B, C, and D of the Latin alphabet, beginning from the fourth ring which was considered the outermost. When a fifth ring situated even farther away from the planet was discovered, it was marked by the letter E.

Data obtained by the American space stations *Pioneer 11*, *Voyager 1* and *Voyager 2* between 1979 and 1981 ushered in a new epoch in the study of the rings. *Pioneer 11* discovered the remotest ring F and *Voyager 1* transmitted an image of rings D and E, the existence of which had been ambiguous until then. Subsequent processing of the photographs made by *Voyager 1* suggested the probability of yet another ring, the seventh.

Then came the real sensation: it was discovered that Saturn had not six or seven wide rings revolving around it, but hundreds of narrow concentric bands, probably 500 to 1 000 in all. The photograms from *Voyager 2* reveal, moreover, that these bands include even thinner ringlets and strands. No less amazing is the fact that not all the rings are ideally shaped: the width of one of them varies from 25 to 80 kilometres.

What accounts for the structure of the rings? One of the more interesting theories is that the banding of the rings into ringlets is due to the gravitational influence of Saturn's moons and moonlets discovered by spacecraft only recently.

A remarkable feature is the comparatively small width of the F ring. Most likely it is also to be explained by the effects of two previously unknown moons about 200 kilometres in diameter. As calculations show, these moons, one situated at the outer edge of the ring and the other at the inner, "drive" the ring particles inside the ring and, confining the ring between them, maintain its structure. This phenomenon has been vividly termed "gravitational shepherding" and the moons responsible for it, the "shepherds".

Another striking feature are the spokes, radially-oriented, wedge-shaped structures extending for several thousand kilometres in the B ring and revolving together with it. The spokes arise sporadically in different locations in the ring and disappear several hours later. The strange thing about the spokes is that if they are part of the ring they had to disintegrate very rapidly, since the ring particles move with different angular velocities, being at different distances from the planet. A thorough processing of the photographs made by space stations shows that each part of a spoke orbits Saturn at the same velocity as that of the ring particles at its radial distance. The narrow end of each wedge-shaped spoke appears to coincide approximately with the distance from Saturn at which the period of an orbiting particle matches the period of Saturn's rotation. The magnetic field of Saturn is locked into the planet and therefore rotates with it. Hence electromagnetic forces may be partly responsible for the spokes. Bursts of static were detected during an experiment aboard *Voyager 1* and they seemed to have originated from sources in the B ring near the regions of intense spoke activity.

Yet another mystery is contained in the F ring. This ring is not uniformly shaped but has kinks, twists and braids in it. This is a phenomenon which can hardly be explained by the laws of conventional mechanics and is most likely also associated with electromagnetic influences.

The discovery of rings around Jupiter and Uranus seems to indicate that such structures are the typical feature of giant planets. It has been suggested that they result from an unfinished process of formation of the planets' satellites from the particles of a precursor cloud situated close to the main bodies of the planets. Other theories have been advanced too.

## Volcanoes in the Solar System

The method of comparison is typical of modern astronomy. In order to study laws governing the structure and evolution of a space object it might prove useful to find another or other objects in space that look like it and see what they have in common and what makes them different. Having established the causes giving rise to the similarities or differences, it will be much easier to get down to the main task on hand.

Similarity points to the common features affecting the evolution of the objects under study and dissimilarity uncovers factors determining the different paths in their development.

Even the most abstract scientific quest should naturally lead to practical application of new knowledge. This orientation of scientific work springs from the social nature of science as a form of human activity. Astronomy is no exception. Probing into events unfolding in space, astronomers think about the earth, first and foremost, especially when they delve into the study of the planets of the solar system, as this helps them to find out more about their own home in the universe. In this light the study of volcanic activity is invaluable.

Volcanic processes are a striking manifestation of our planet's deep-seated life exerting an enormous influence on many geophysical processes. One can get an idea of the scale of terrestrial volcanism from the fact that there are something like 540 active volcanoes in the world, that is, volcanoes that erupted at least once over the period of recorded history. Of them 360 are situated in the "ring of fire", the volcanic ranges nearly surrounding the Pacific Ocean, and 68 on the Kamchatka peninsula and the Kurile islands.

In recent years it has been established that incomparably more volcanoes are to be found on the ocean floor, at least 200 000 in Central Pacific alone.

The amount of energy released during just one average eruption is comparable to the energy of 400 000 tons of fuel equivalent. The energy produced in a large-scale eruption is roughly equivalent to the burning of 5 000 000 tons of coal.

The numerous solid particles blasted during eruptions into the atmosphere and scattering solar rays produce a dramatic effect on the amount of heat reaching the earth. Some of the available data indicate that the lengthy cooling periods in the history of our planet were often preceded by large-scale volcanic activity. Contemporary scientific information shows volcanic activity to be taking place also on other planet-type objects in space which in their nature and structure resemble the earth.

The moon, our closest neighbour, demonstrates much similarity in its evolution with our planet. A comparative study of this satellite, therefore, should be especially revealing.

It will be recalled that according to the information returned by lunar probes, most of the ring-shaped craters on the surface of the moon are of impact origin. On the other hand, clear traces of volcanic activity have also been discovered on its surface. Volcanic basalts, for instance, as well as solidified lava flows are a conspicuous surface feature. Furthermore, there are reasons to believe that the mascons, or mass concentrations discovered by means of the artificial satellites of the moon beneath the *maria*, are nothing but solidified lava chambers.

Other features of the lunar surface probably indicate an even more intimate connection with volcanic activity. They are the tumescences, or low round elevations of the terrain, on some of which markings resembling calderas (areas of collapsed rock around craters) can clearly be seen. Similar structures, called the laccoliths, are rather common also on earth. They are elevations of the earth's crust resulting from terrestrial volcanism. Some hills in the Northern Caucasus—Mashuk, Beshtau and Zmeika among them—belong in this category.

In general the lunar relief owes its features to both external (exogenous) and internal (endogenous) processes. The bowl-shaped seas on the moon's surface are a result of the combined action of the two. According to scientists, the lunar seas evolved in several stages. First, there were collisions with big meteorites which left craters each several tens of kilometres deep. With the passage of time the elasticity of the moon's crust caused the floor of the crater gradually to straighten out and 500 million years after that lava burst forth through crustal rock from a depth of about 200 kilometres. Filling the bottom of the crater and gradually cooling down, the lava formed a smooth surface. The origin of drowned craters on the moon, that is craters with a flat bottom, can be explained by roughly similar mechanisms.

Studies of the photographs made by the moon's artificial satellites reveal areas of the lunar surface marked by lava flows and lakes. Scientists believe that active volcanic processes took place mainly during the first one and a half billiod years of the moon's history. This view is supporten by assessments of the age of lunar rock containing volcanic ejecta. It is at least three billion years old.

Clear traces of volcanic activity are to be seen on the photographs of Mercury, the closest planet to the sun. Its surface is dotted with an astonishing number of craters. Although the craters are of impact origin, traces of outpourings of lava are discernible on the bottom of some of them.

Some data indicate that volcanic activity is continuing on Venus even now. It will be recalled that the temperature at the Venusian surface is about 500 degrees Celsius, which is most likely due to the greenhouse effect: accumulation of solar heat in the lower Venusian atmosphere owing to the cloud envelope surrounding the planet. But it may also well be that volcanic events, especially hot lava flows, are another contributing factor. The large amounts of solid particles, which, according to some data, are present in the atmosphere of Venus may also be of volcanic origin. It must be noted, furthermore, that 97 per cent of this atmosphere is carbon dioxide, the gas released during volcanic eruptions.

Other important findings include the discovery of three "light" spots or areas that are better reflectors of radiowaves. One of them is 400 kilometres across and together with the other two may have been formed by lava flows.

A 100-kilometre caldera most likely of volcanic origin has been discovered on the top of the highest Venusian mountain in the Maxwell mountain massif.

Over the Beta area (named so after the second letter of the Greek alphabet) considerable gravitational perturbation was recorded. On the earth such phenomena are observed in areas above young, but not necessarily active, volcanoes. It has also been suggested that the numerous lines radiating from the centre of Beta are solidified lava flows which means that this area may be a shield volcano 800 kilometres in diameter at the base and a caldera 80 kilometres across at the top.

Additional evidence in support of the view that volcanic events are currently taking place on Venus was collected by the Soviet *Venus 11, 12* and *13* stations which registered numerous lightnings in the vicinity of some Venusian mountains, a phenomenon often observed during terrestrial volcanic eruptions.

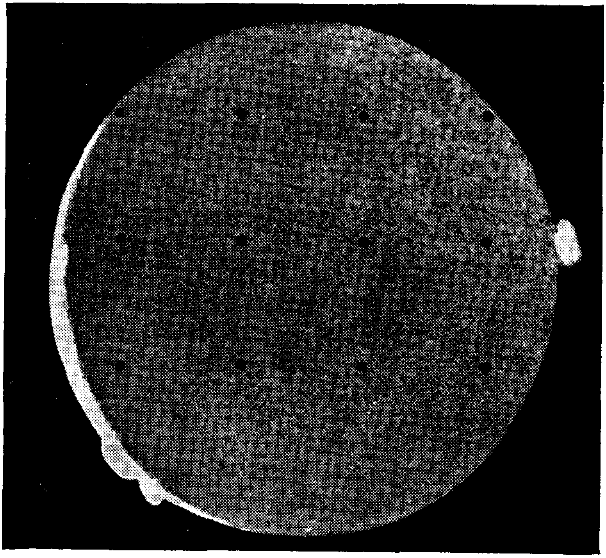
Then there are the great speeds of motion of gassy masses in the Venusian atmosphere. While the planet's rotation is rather slow (one rotation in 243 earth-days) the rotation of the atmosphere takes only four or five earth-days. Such hurricane speeds must consume vast amounts of energy and it may be assumed that this energy is supplied not only by solar radiation but also by the planet's interior.

Some data on Mars, mostly obtained by spacecraft, indicate that on this planet too volcanic processes had played an important part in the formation of the surface features. Some Martian craters have central elevations with a dark spot on the top. It may well be that they are extinct volcanoes.

Several of the Martian mountains are definitely volcanic cones, the most conspicuous of them being Nix Olympica ("Snows of Olympus"), which is about 24 kilometres high. It will be recalled for the sake of comparison that Mount Everest, the loftiest peak on earth, is less than nine kilometres high. In 1971 when Mars was shrouded by dust during a violent storm the cone of Nix Olympica could be seen above the dust canopy.

Another three gigantic extinct volcanic cones almost as tall as Nix Olympica are situated in the same area of the Martian surface. Scientists think that they erupted tens or hundreds of millions of years ago. The eruptions were accompanied by enormous discharges of ash which must be covering huge areas of the Martian surface now. The great height of the volcanic mountains on Mars obviously speaks of the great scales of the volcanic processes there resulting in the deposition of enormous amounts of volcanic material.

The eight or nine active volcanoes discovered on Io, one of Jupiter's moons, are in the category



Volcanic eruption on Jupiter's moon Io (Photograph by *Voyager 1*)

of the most spectacular events recently registered by spacecraft. The columns of dust and hot gas reach heights of up to 200 kilometres.

While terrestrial volcanism is associated with the heating of the earth's interior mainly owing to radioactive decay, in the case of Io heat is most likely derived from tidal perturbations caused by Jupiter's neighbouring moons in its powerful gravitational field.

One remarkable fact is that although several months had passed between the times the region of Io was visited by *Voyager 1* and *Voyager 2*, six of the volcanoes discovered during the first photographing were still erupting when photographed the second time. An interesting hypothesis explaining the incredible duration of the eruptions has been advanced by a Soviet astronomer, G. A. Leikin.

If Io has its own magnetic field, it can be assumed that it may capture particles from the Jovian radiation belts. It is also possible that magnetic anomalies may exist in areas of volcanic eruptions which may cause concentrations of such particles precisely in these areas. Their action may cause evaporation of matter facilitating volcanic phenomena.

Titan, a satellite of Saturn and one of the biggest satellites in the solar system, may be another likely place for volcanic events. If so, the "hot lava" flows there must consist of liquid methane and solutions of ammonia.

Thus, for all their diversity, volcanic processes must represent a natural stage in the evolution of planetary bodies of the terrestrial type. This is why a study of such processes on other planets of the solar system will doubtlessly shed light on the laws governing the processes evolving in the earth's interior.

## The Moon and the Elementary Particles

Cosmic rays are a unique natural laboratory for physicists studying the structure of matter. The fluxes of cosmic radiation that are piercing the universe may contain particles charged with such energy which even the most powerful accelerators have failed to produce so far.

However, this "laboratory" also has a significant shortcoming: if we are after particles possessing rare qualities, we may have to wait for many decades. We cannot know in advance when the particle in question chooses to appear precisely in the point of the universe where the recording device is mounted at the given moment.

Physicists try to make good this situation by attempting to capture the particles with the aid of thick nuclear emulsion plates installed in mountainous regions. Cosmic rays passing through them leave their tracks.

But it is too early to say anything definite because the experiment has not been conducted for a sufficiently long time, and besides, even the loftiest mountain tops are not outer space. Not all the particles can break through the earth's atmosphere. True, today scientists have the wherewithal to hoist their instruments: high-altitude aeroplanes, sounding-balloons and various space probes. But the planes and balloons can only be used for short-time observations; as for space probes, they have come into practical use comparatively recently.

The space probes may cause a virtual revolution in the study of cosmic rays. They have given researchers a laboratory where a registration of cosmic rays has been going on for billions of years. This laboratory is the moon.

As we know, the lunar surface, unprotected by an atmosphere, is constantly bombarded by the particles contained in cosmic rays. Lunar rock retains traces of their impacts. The study of the traces is under way at present.

Of great interest are the first communications

Tracks drawn by elementary particles in photoemulsion

on the subject. Indian scientists D. Lal and N. Bhaudari, after subjecting rock samples returned from the Moon to special treatment, have discovered unusually long tracks of some particles in the crystals of lunar matter. One of them is 18 microns long. It will be recalled, for the sake of comparison, that the particles released during spontaneous uranium fission produce tracks up to 14 microns long.

An american astronomer, B. Price, also studying lunar rock, discovered a track 50 times longer.

What particles could have left such long tracks?

As far as the tracks discovered by the Indian scientists are concerned, it is not impossible that they were left by nuclear fission fragments of superheavy transuranium elements.

It is general knowledge that for a long time uranium had occupied the last, 92nd, place in the Periodic Table. Owing to the advances of nuclear physics, scientists have been able to synthesize a series of transuranium elements.

The major difficulty of such a synthesis is that the transuranium elements are extremely unstable. The heavier the nucleus, the faster its decay. Therefore, it could be expected that it would be extremely difficult or plainly impossible to produce elements with numbers higher than 103. But when a 104th element, named "Kurchatovium" was synthesized at Dubna in the Soviet Union, it appeared that its lifetime was about three seconds.

On the strength of this and some other facts theorists assumed that there should exist certain "isles of stability" in the world of transuranium elements, that is, atoms possessing stable electron shells, and that they should be situated between the 106th and 114th, and between the 124th and 126th elements.

But if some of the transuranium elements really possess long lifetimes, then they must also exist in nature. Originating in some violent space process, for example, they could have reached the earth. Hence, it would be sensible to look for their tracks.

In recent years such a search has been conducted in the earth's rock, the Arctic ice and early sedimentary deposits on the ocean floor and even in old glass and mirrors.

But perhaps the conditions existing on our natural satellite, the moon, are the best for such experiments.

What monster of a particle could have left a track almost a millimetre long in lunar matter? Could it be the mysterious monopole, the hypothetical particle predicted by the well-known English theorist Paul Dirac?

As is known, both positive and negative electric charges can exist independently of each other. In nature we find electrons and positrons, protons and antiprotons. At the same time the magnetic charges, the north and the south, are bound up inseparably. No human hand has yet been able to create or observe a monopole and antimonopole, i.e., to separate the magnetic poles from each other.

According to Dirac's calculations, the magnetic charge of a monopole has to be something like 70 times more powerful than the electric charge of an electron. This means that the monopole can acquire colossal energy even in very weak magnetic fields. Therefore, having obtained a monopole, we could create, by rather elementary means, uncommonly powerful accelerators. Moreover, if it were possible to prove the existence of a monopole, it would be possible to solve many problems in the theory of the origin of cosmic rays, particularly, to explain the tremendous energies of some cosmic particles.

Dirac also calculated that the monopoles had to have considerable mass and interact with each other several thousand times more intensively than elementary electric charges. It follows that to obtain a pure monopole and antimonopole is much more difficult than to produce an elementary particle. But on the other hand, the probability of their mutual annihilation is likewise far smaller. By virtue of this fact the monopoles could be perfect atomic artillery "shells" to be used to bombard various elementary particles. Such "shells" could be accelerated to gain tremendous energies and used many times over. This speculation fascinates many physicists who have set out on a search for the monopole. But no progress has been reported yet.

The intriguing practical possibilities apart, the question of whether elementary magnetic particles exist has a great theoretical interest. Just as the finding of a monopole, the discovery of a law ruling out the possibility of its existence, would be of tremendous importance for the development of our physical conceptions of the structure of the world.

## The Invisible Satellites

Different planets "possess" different numbers of satellites or moons. But their distribution in the solar system is clearly "unjust". The giant Jupiter has 15 and according to some astronomers Saturn has more than 20 moons. The closer to the sun, the smaller the number of the satellites. Mars has only two satellites, Phobos and Deimos; Mercury and Venus have none at all.

The earth has only one natural satellite, the moon.

As a matter of fact we must first establish what should properly be considered a satellite. We are used to seeing our moon as a spheric body, but generally speaking, a satellite may have a different shape. The important thing is for it to be bound to the given planet by gravitation.

What shape can a solid body have in space? It can be a shapeless lump, it can be dust or a dust cloud. If such lumps are taken for satellites, then the earth may have several of them. It has not been possible to detect them although there is some indirect proof that they do exist.

What about dust satellites?

Back in the 18th century the outstanding French mathematician Lagrange, studying the "three body problem", arrived at the conclusion that under certain conditions these bodies may form a kind of an equilateral triangle in space.

It goes without saying that with time each one of the three bodies will be moving along its orbit in relation to the common centre of mass. But while in motion, they still will remain the vertices of an equilateral triangle. The triangle proper will be constantly changing in figure, contracting or expanding and turning in relation to the centre of mass. But it will always remain equilateral. In this way, a three-body system is characterized by what may be termed "points of equilibrium".

And what if it is a two-body system, such as the "earth-moon" system? There, too, a potential "point of equilibrium" exists, making up, together with the other two, the vertices of an equilateral triangle. And since on a plane where there are two bodies in motion it is always possible to build two equilateral triangles with two common vertices at the points that are these bodies, it is obvious that this two-body system must -always have two "points of equilibrium", al though they may remain "unoccupied" for the time being.

However, if a body happens to get into a Lagrangian point and immediately lose its speed in relation to the earth and moon, it will be caught in a sort of a gravitational trap and will remain there forever or at any rate, for a very long time.

At first, when the "trap" is empty, it does not function properly and the particles pass freely through this "zone of equilibrium" and continue on their way. But gradually, as the "trap" is filled up with matter, the "capture" process becomes faster and faster. Now the flying particles may collide with those already caught in the invisible net, lose speed and add to the "catch".

Although this process is extremely slow, it could have been expected that over the hundreds of millions of years an appreciable amount of matter could have accreted in the Lagrangian points of the "earth-moon" system, for numerous dust particles and probably even bigger objects are moving in circumterrestrial space.

Satellites were discovered in the Lagrangian points of the "sun-Jupiter" system as early as the break of the century, and asteroids were observed in the vicinity of each of them. They were all given the names of heroes of the Greek epos of the Trojan War. The bigger group began to be called the "Greeks" and the smaller, the "Trojans".

For a long time scientists had failed to spot any such satellites of the earth, although the probability had been predicted by theory. That was due to several reasons. A satellite, such as the one in question, can be seen only when the corresponding Lagrangian point is situated in the region of the celestial sphere opposite to the sun, and at the same time far enough from the bright path of the Milky Way. Moreover, it has to be a moonless night.

Such good coincidences are exceedingly rare in nature. For many years astronomers had been photographing Lagrangian points but could discover no traces of solid matter. It was only a few years ago that they finally succeeded in photographing the earth's "invisible satellites". They turned out to be rather impressive: the diameter of each of them is comparable to that of the earth itself.

True, by cosmic standards the mass of these dust clouds is quite small: a mere 20 000 tons; as to their density, it is even less imposing: one dust particle per cubic kilometre. No wonder it had been so difficult to discover them.

And yet, the clouds of matter situated in the vicinity of the "points of equilibrium" will most likely have to be reckoned with in selecting space paths.

On the other hand, there is the intriguing prospect of building orbital stations at Lagrangian points. It will be practically unnecessary to correct their positions for a long time. But in that case it may perhaps become important to get rid of the matter accreted in these points for it may be dangerous for the station and may interfere with scientific observations.

## Is There Motion by Inertia?

Galileo's discovery of inertia played a crucial role in the study of the motions of celestial bodies, and particularly, of the planets of the solar system.

In the times when the law of inertia had not yet been postulated, great Kepler was looking for the mysterious force that was ever pushing the planets ahead and not allowing them to stop in their endless motion around the sun.

Today it is an established fact that the revolution of the planets is combined of two motions: uniform motion in a straight line and motion caused by the attraction of the sun.

Now here is rather an unexpected question: is there motion by inertia in the actual universe?

I have never forgotten one incident from my school years. I think I was in the 8th form then and we were studying Newton's three laws of motion.

For our concluding class the teacher, an intelligent man with a fine knowledge of physics, brought a projector and a box of slides.

"I'll be showing you pictures", he said. "You will see situations demonstrating Newton's three

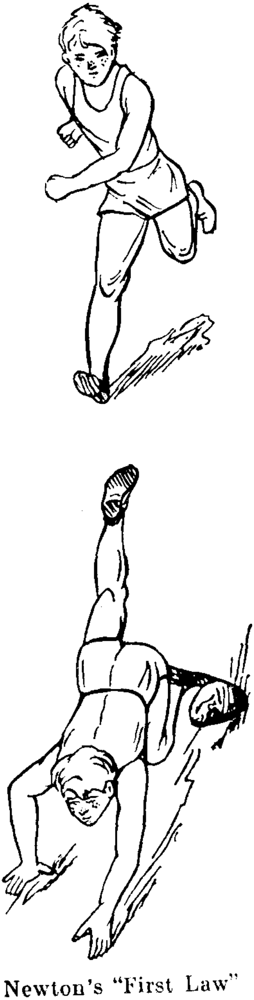


Illustration to Newton's "First Law"

laws. Take a good look at them and tell me which law each picture illustrates. So, let's begin".

The first picture on the screen showed a boy falling down, his arms outstretched. He had been running when he tripped over a stone.

"So, which law was meant here?"

"The first", we all answered in chorus.

We had every reason to give that answer. A few days before we saw the explanatory note to the set of slides, which was entitled "Newton's Three Laws." Whoever had compiled it, had written in the annotation to No. 1 slide, "The falling boy", something to this effect: "Illustration to Newton's first law, the law of inertia. The boy has tripped over a stone on the run, but his body continues to move by inertia and the boy falls".

"Granted", the teacher said and called me to the blackboard.

With much confidence I began:

"The running boy has stumbled over a stone..."

"Is it the first law you say?"

I nodded.

"OK. In this case let us hear the way it reads."

"Every body remains in a state of rest or of uniform motion in a straight line, unless it is compelled by impressed forces to change that state", I hammered out the Newtonian definition in one breath.

"Right. And now let us translate it into common physical language. If no external force is impressed on a body, its acceleration is zero. Correct?"

"And what about the state of rest? You haven't said anything about it", someone called from his place.

"Rest is a special case of motion, when speed equals zero. Thus, what does and what does not the first law speak of? It only speaks of the case when the forces are zero. And nothing else. And what if the forces are not zero? The first law 'knows' nothing about it".

That was something new. Until that day we had simply tried to memorize the three laws and to learn to solve problems concerned with them. But now Newton's law seemed to have opened up from a new angle. Suddenly we realized that the boy's fall in the picture had nothing to do with the first law.

If the boy has got his foot caught on a stone, it means that a force acted on him and there was acceleration in the boy's motion. From that moment his motion ceased to be uniform and in a straight line. And the law said nothing about such a case.

An important conclusion follows. We can speak of motion by inertia only when the given body is not impressed by absolutely any forces. Or at least when the resultant force of all the forces is zero.

We are all used to hearing statements like these: "The engines died and the rocket continued moving by inertia", "The driver braked, but the car continued to skid along the ice-covered road by inertia."

Are such statements justified? Perhaps they are, as far as fiction is concerned. In actual fact, both the rocket with the dead engines and the car after braking were moving with acceleration. In the case of the rocket this acceleration (positive or negative) had been imparted to it by the earth's gravitation and in the second, negative acceleration had been impressed on the car by the force of friction originating between the tyres and the road surface.

Strictly speaking, we can hardly point out even one case of motion "by inertia" in a pure form in nature, which would be in strict conformity with Newton's first law. For any object, no matter where placed, is always subject to the gravitational influence of a host of celestial bodies.

The law will be confirmed only in cases when allowance is made for a certain degree of idealization, that is, if the forces acting on the given body are so insignificant that they exert practically no influence on its motion and can be ignored.

Without this important reservation Newton's first law is practically never proved in nature, for it is only a borderline case of accelerated motion.

## Orbital Paradoxes

We know that the motion of celestial bodies is laid down in Kepler's laws and in Newton's law of gravitation. These laws have become so much part of our mentality that we can imagine ourselves capable of foreseeing much in the motion of space objects even without calculations, on the strength of the physical contents of these laws. Sometimes we can even succeed. But in many cases calculations produce results widely different from those we almost believed to be obvious.

A spacecraft is to start from on board an artificial earth satellite, revolving around the planet along an elliptical orbit. What is the best moment for the craft's lift-off—when the satellite is in the apogee or perigee?

The answer would seem obvious: in the apogee, for the farther an object from the earth the weaker the earth's gravitation, the lower the escape velocity, and, consequently, the smaller the amount of fuel needed.'

But we must not forget that according to Kepler's second law, a satellite moves along its orbit with variable speed, which is the lowest in the apogee and highest in the perigee.

What is better: lower escape velocity in the apogee with a smaller store of initial velocity, or higher escape velocity in the perigee, but with a bigger store of initial speed? We cannot answer this question on the basis of our theoretical knowledge. It requires precise calculations.

It is necessary to calculate, for the apogee and perigee, the differences between the artificial satellite's velocity and the escape velocity in the given point of circumterrestrial space and then compare the differences. Obviously, a launching project will be preferred for which this difference will be the smallest.

Let us consider an example. A spaceship is to be launched from on board an artificial earth satellite orbiting at 330 km in the apogee and 180 km in the perigee.

The escape velocities for the different altitudes have long been calculated and entered in special tables. For our particular satellite the table gives escape velocity of 11 040 metres per second in the perigee and 10 918 metres per second in the apogee.

Now it will not be hard to compute the satellite's velocity in the perigee and apogee: 7 850 and 7 680 m/s.

Let us find the differences we need:

for the perigee, 11 040—7 850 = 3 190 m/s;

for the apogee 10 918 — 7 680 = 3 238 m/s.

Thus, it is not the apogee but the perigee which is the better point for the launching.

Curiously, the more pronounced an orbit's ellipticity, the greater the advantages of a perigee launching and the greater the paradoxical aspect of the situation. For example, in the case of a strongly elongated orbit, say, with the perigee at 40 000 kilometres from the earth and the apogee, at 480 000 kilometres, which is beyond the lunar orbit, it is four times easier to develop escape velocity and break out of the earth's gravitational trap in the region of the perigee than of the apogee.

This fact is a good illustration to the fallaciousness of many "obvious" conceptions. But it must be emphasized that this paradox is true only in the case of one and the same satellite moving along the given orbit.

It is interesting that a reverse paradox will be observed when the artificial satellite is on its return path. It would seem that it would be more advantageous to begin the braking the moment the satellite is in the perigee, that is, the closest to the earth.

However, calculations prove that in this case, too, the principal factor is not the distance from the earth but the speed of the satellite's motion in orbit. It is lower in the apogee and so, as far as fuel consumption is concerned, it is better to start on the descent from the apogee stretch of the orbit. True, this is a somewhat idealized case, since it does not take into account the speed of the satellite on entry into the dense layers of the atmosphere.

Let us consider another paradox of space navigation, defying accepted principles of terrestrial mechanics. Generally we believe that the faster we move, the faster we cover the given distance. This belief is not always true in the case of a spacecraft moving within gravitational fields of celestial bodies, as for example, during flights from earth to Venus.

It is known that the earth orbits the sun at a velocity of about 29.8 km/s. Therefore a spaceship launched from an orbit of an artificial earth satellite will have the same initial velocity relative to the sun.

Venus's orbit is closer to the sun and for this reason, in order to reach it the ship's velocity in respect to the sun should not be increased as in the case of a flight to Mars, but reduced. But this is only the first "half" of the paradox. It appears that the lower this velocity, the faster the ship will reach Venus's orbit. As computations show if departure velocity is 27.3 km/s relative to the sun, the flight will take 146 days, and if it is 23.8 km/s, it will only take 70 days.

In this way our earthly ideas are far from being always applicable to the motion of space vehicles.

## How About a Game of Chess? (science fiction)

The *Omicron*, a passenger spacecraft with a crew of 12 and 360 passengers on board, was on a regular flight to Megos. Captain Meng and navigator Gaskondi, gazing silently at the screen, both realized the situation was hopeless. The error had occurred at the moment they left hyperspace. Something had gone wrong with the ship's controls—the tiniest deviation from the program, a barely noticeable fluctuation—but that was enough to throw the ship five parsecs away from the calculated spot in space. And now they found themselves captives of a white dwarf, a small star of monstrous density and gravitation, which, it seemed, had been waiting specially for them.

All the rocket engines were going full blast but that only saved the *Omicron* from falling into the flaming void and was not enough to break the chains of gravitation. Now the *Omicron* was cruising around the dwarf along a closed orbit, at a distance of about 20 000 kilometres from the centre of the star, and all the power of the ship engines could not tear it out of the star's clutches. As if that was not enough, the time allotted for their flight was running out as was the energy essential to maintain the protective field which was shielding the ship from the scorching breath of the dwarf.

"How long more?" Meng asked sharply, his eyes fixed on the screen where a red dot was describing a neat ellipse around the star.

Used to understanding his captain at a hint, the navigator quickly pushed several buttons on the computer keyboard.

"Six and a half hours... Should we send out a SOS, perhaps?"

The dwarf was too close. Meng could almost feel its hot breathing even though the ship had the protective field—for the time being... In six and a half hours the energy source would have been exhausted and then...

"Could we weaken the field?"

"It's minimal as it is", Gaskondi replied crisply. "Well, what about the SOS?"

The captain said nothing and sank into his seat. His eyes were closed. He was faced with a problem which was out of reach of even the most sophisticated computer.

Of course he was supposed to give a SOS—that's what the "Regulations for Space Navigation" said. But he knew for sure that right then there wasn't a single ship in their sector which could rescue the *Omicron*. The nearest station was on Megos, but the distance was such that a standard radiogram would take months to get there. The distress signal had to be sent via hyperspace and that would require too much energy and energy was what promised them a few more minutes of protection against the white dwarf.

And yet, Meng would have taken the risk of a hyperspace radio transmission had there been a ghost of a hope: the galactic fleet had only four craft capable in this situation to reach the *Omicron* to refuel her or to take her in tow without themselves getting into the gravitational trap, and all four, as Meng knew only too well, were in far sectors and would by no means be able to get to the ship in time.

"We could save some time," Gaskondi broke the silence, "thirty minutes or so."

The captain looked up, an unspoken inquiry in his eyes.

"If we remove the load."

"No, it's too dangerous, there are women and children among the passengers," he replied firmly.

That was another problem on which no one but the commander could take a decision. Passengers! They were all resting in their cabins now, sure that in a day or two they would reach their destination. Six and a half hours was all that was left to them. Should he tell them? Or would it be better to leave them in their unsuspecting ignorance to the end?

Many a time over the years of his service in space travel the captain found himself in a critical situation, but those were situations which had a way out. Everything depended on his experience and resourcefulness. Until now the captain had always managed to find the best course of action within moments. But not this time. That much was clear from the simple calculations which even a student could make. Nothing depended on him now. He could try whatever he would but the outcome would still be the same. That meant they would have to resign themselves to their fate and just wait helplessly for the moment the star would get their ship and it would disintegrate in a bright flare.

To give up without a fight? Nothing like that had ever happened to Meng.

"But such a thing happens only once," he thought bitterly.

No, this won't do. He must put up a fight, not give in, even if the situation seemed hopeless.

"Have you gone over everything once more?" he asked the navigator.

Gaskondi turned his head slowly. For the first time since the instruments told them of the imminent catastrophe the two men looked each other straight in the face. Gaskondi shrugged.

"You know perfectly well yourself."

"But still we must check on all the possibilities."

"But this is elementary!" Gaskondi lost his temper. "What possibilities can there be?!"

Captain Meng knew as well as his navigator that there could be none. This was a classic case, one studied from every angle at the dawn of the era of space navigation and largely ignored in recent times. The latest types of spacecraft were taking care of this particular danger. No one had been caught in a gravitational trap for at least fifty years. The *Omicron* was the only luckless one. But could the fact that theorists had ignored the problem for such a long time also be their only chance? Science had not been marking time. If they analyzed the hopeless situation in the light of modern knowledge, they could probably find some way which classical navigation had overlooked.

At any rate, they must search for it. But how could he persuade Gaskondi? He was an excellent worker, faultless. Meng could not remember him ever violating even a letter of the "Regulations". But that was also his weak point. One who makes mistakes and finds ways to correct them learns how to handle unforeseen situations whether he wishes to or not. But Gaskondi did not make mistakes—he had one allmighty god with him, the "Regulations".

"Alas," the captain was thinking, "his brain is not programmed to make discoveries." Another thing he regretted was that he himself had always been interested in the engineering side of the matter and paid considerably less attention to the theory of space navigation. Of course he had sound knowledge of the fundamentals and could replace Gaskondi in case of need, but now this knowledge was not enough.

"So, your suggestion is that we should wait, just sit and wait and do nothing?" Meng spoke without looking at the navigator.

"I suggest that we give a SOS," Gaskondi repeated sullenly. "Just as indicated in the 'Regulations'."

"No," Meng replied curtly, "We'll have enough time to report our death yet. Till then we must do something, even in defiance of the 'Regulations'."

Gaskondi looked hurt.

"I would give much to see..."

Meng got up and went to the navigator's seat.

"Now just let's put our heads together. What if..."

They hadn't noticed Verin enter the control room and now discovered him standing at the main panel gazing at the screen.

The passengers were strictly forbidden to enter the command module. But Verin was not an ordinary passenger. The *Omicron* had been built on the basis of his physical theory. He was the author of numerous original ideas which had produced a considerable influence on the development of physics and astrophysics. He was going to Megos to give a series of lectures on the theory of hyperspace at the local university.

But still he was a passenger on the *Omicron* and Meng thought with some concern that now their predicament had ceased to be a secret.

"A curious situation, isn't it?"

In the circumstances his words sounded rather strange, especially since his tone had a quality of sarcasm or even some inexplicable satisfaction.

Gaskondi shrugged.

"Not enough energy, is it?" Verin asked finally forcing himself away from the screen.

"As you can plainly see," grumbled Gaskondi who was in no mood for courtesies.

"And the heat protection is petering out in a few hours?"

"In six and a half," Meng replied without thinking.

"I see," the theoretician drawled reflectively, "M-m, I see..."

His deep-set eyes sparkled with excitement and Meng thought he looked like a hunter who saw a rare prey. It seemed Verin was not a bit worried about the fact that in this case he was the prey and not the hunter. He stood there lost in thought, gazing into the distance beyond the solid wall of the ship, as if regarding something he alone could see.

"They are right, it seems, when they say he lives only by his science", Meng thought.

But that was not quite true. When Verin's eyes were on the screen his thoughts were far away, on his home planet where his old mother was soon to learn about his death. A moment later, he pulled himself together and, forcing everything but the challenging problem out of his ingenious mind, began to search for a solution. The problem which the absurd accident was confronting him with could have no positive solution by any standards. But it was precisely this kind of problems that Verin had grappled with all his life.

"May I use your computer?" he asked recalling himself from his thoughts.

"All the same..." Gaskondi began but Meng silenced him, quietly putting his hand on the navigator's shoulder.

It seemed Verin hadn't even noticed the incident. He went to the panel and began pushing the buttons rapidly, all the while looking at the display.

Meng tried to follow his computations but was soon lost. The only thing he managed to grasp was that Verin's calculations had no direct connection with their situation.

"We're all funny here, ridiculous," the thought struck him suddenly. "We have only six hours to live and Gaskondi there is all worked up about instructions, Verin is deep in some abstract reasoning and I'm watching them both coldly as though nothing is happening. But perhaps it's all because the value of time is relative and six hours is not so little?"

Suddenly the theorist turned away from the panel and said, glancing at the navigator:

"Do you think the problem is insoluble?"

Gaskondi was touchy. He searched Verin's face for any signs of irony and finally replied:

"The case is elementary. There are two forces at work: the dwarf's attraction and our thrust. It's perfectly clear. The thrust is obviously inadequate to develop escape velocity."

"Yes, that's it," Verin muttered after a while. "Solution of a problem depends on how the problem is posed. The way you treat your problem," he nodded in the direction of the panel, "it is indeed insoluble."

"I didn't pose it," Gaskondi began, but Verin wasn't listening. He was back to his mental exercise, having immediately dissociated himself from everything around.

It was then Meng had the first glimmer of hope. He knew better than anyone else that only a miracle could save them. And since a miracle was not likely to happen, as they never really do, a super-original idea was needed, something totally unexpected, outstanding. And if anything like that was forthcoming, it could only be from Verin.

The commander looked at the physicist with respect. This small frail man, who looked so unimposing and insignificant, seemed to see what was beyond other people's range of vision.

"Do you know the joke about the dog?" Verin broke the silence.

No one said anything and Verin continued:

"Suppose," one physicist said to another, "that a dog has a frying pan tied to its tail. If the dog runs the pan will bang on the road and boom and rumble. With what speed must the dog run not to hear the din? Strange as it may seem, the other physicist could not find an answer. And what do you think," he turned to Gaskondi, a mischievous smile on his face, "how fast must the dog run?"

"I don't know," the navigator mumbled. Clearly, he was finding difficulty keeping his temper.

He glanced at Meng and noticing his expression of intense concentration, forced himself to say:

"Apparently it must run at supersonic speed."

"Exactly," Verin began to laugh, "that's exactly what that other physicist thought. And the right answer is quite simple: the speed must be zero. Elementary. The whole point was in the way the problem was worded: 'At what speed must the dog run?' Speed... That's the trick. Even physicists sometimes forget zero speed is speed nonetheless..."

The unassuming navigator was staring at Verin incredulously. Meng did not quite know how to react either, although he was perfectly sure that the physicist told the joke not for fun, that for him it was something like mental relaxation, a way of letting his consciousness rest while his subconscious was working.

"On the other hand," Meng was thinking, "there is probably good reason why he remembered this and not some other story. Maybe there is something in it after all."

As if in confirmation of the commander's optimistic supposition, Verin again turned his attention to the computer, and with an expression of almost childish concentration on his face, like a virtuoso pianist, pounced on the computer keyboard.

Meng and Gaskondi waited in silence. Finally Verin pushed away from the computer with a sigh of relief and a satisfied glint in his eye.

"Do you play chess?" He turned to Meng.

"Yes."

"Then you must know about chess problems and compositions. Consider this case. The situation on the board is hopeless for one party—the game is lost. There is one move, however, which at first sight seems the shortest way to defeat, but it is exactly this paradoxical move which can bring the losing party victory."

Meng was positive now that Verin had indeed stumbled upon a solution.

"Well?" He was unable to contain his impatience.

Verin was looking at him steadily.

"We must make that move now," he spoke slowly as if weighing up the pros and cons once more.

No one spoke. The quiet in the control room was absolute. The commander stood motionless gripping the back of a seat.

"We'll need all the boost we can get," Verin said. He scribbled a few figures on a sheet of paper and handed it to Meng.

"But that's not going to help any," Gaskondi muttered in confusion, "will only make the orbit more elongated, probably."

"Quite so," Verin said.

"But the boost will take all our energy. And this means the heat protection..."

"Just a minute," Meng cut in.

"What difference does it make if it happens in six hours or in three..." he thought.

But Meng had deep trust in Verin. Without any hesitation he reached out for the main control board and one after another moved four red levers several notches.

Gaskondi tensed.

Now they could hear humming as the engines were started, followed by the click of the overload protection relay being switched on.

"Could you give us some explanation now?" Meng asked.

"The *Omicron* consists of two isolated parts, right?" Verin began slowly.

"Yes, that is so," Meng replied. "The first houses the command module and the engines and the second the cabins and other quarters."

"And these parts can be separated and moved a considerable distance away from each other, am I right?"

"Yes, in case of emergency or if the power plants are in need of repairs. The two parts are withdrawn by means of a special pulser."

"What maximum distance between them can we get?"

"One hundred and fifty kilometres."

"One hundred and forty will suffice," Verin muttered.

"Do you mean to get rid of the passenger module?" Gaskondi finally managed to join in the discussion, "but even so we won't have enough thrust."

"Of course not," Verin spoke with emphasis, "that would be too simple. The dwarf is not going to let us off so easily. No, I have something else in mind."

"We are wasting time," Meng interfered, "perhaps, we should..."

"No, we have all the time we want," Verin said unperturbed. "Now, to my idea, I'm sure you are familiar with the principle of a pulsating spacecraft."

Gaskondi and Meng exchanged a puzzled look.

"That's it. It's a very old and long forgotten idea," Verin remarked.

"I think I remember something of the sort vaguely," Meng said. "I stumbled on it in an old text-book. If I'm not mistaken, the idea is that the spacecraft is not a material point, but a body whose mass is distributed over its whole length."

"Yes, yes, quite so," Verin began to speak excitedly. "If we separate our ship into two parts, then the resultant force of gravitation applied to them will be smaller than the force acting on the *Omicron* at present."

He pronounced every word very clearly as if speaking before an audience.

"And this means," Meng echoed, "that if the ship is 'stretched out' it will be affected by a repulsive force, won't it?"

"And if the two parts are joined together in the apogee and separated in the perigee the *Omicron* will be pushed off its Keplerian orbit and start moving along an unwinding spiral."

"I say," Meng exclaimed.

"Now I remember too," Gaskondi suddenly broke in. "Marvellous, superb, great." He laughed nervously. "But if I remember correctly it will take a ship several years to overcome even the earth's gravitation in this manner. And the dwarf?.."

"That's the whole point," replied Verin, unruffled.

"Incredible," Meng was thinking to himself. "For a man to think so clearly and see so far in such a situation."

"That's the whole point," Verin repeated. "Gravitation in this case works for us. The more massive a star or planet, the faster escape velocity will be achieved. And that's the paradox."

"How many hours will we need?" Meng asked.

"An hour and a half, not more."

"You are a genius," the captain smiled and took his seat at the main control board.

"The only thing now is to determine the optimal moments for the separation and rejoining," Verin warned.

"Yes, I see," Meng was already deep in calculations. "I'll be ready for the operation in six minutes."

Never had such a sight been observed before: the giant spaceship broke up into two halves which were set in motion, now drawing close to each other, now drifting apart. Very gradually the fatal orbit which the *Omicron* was travelling began to unwind.

The great elemental force of gravitation conquered by the human intellect was taking the ship farther and farther away from the blazing abyss.

## Gravitation Against Gravitation

One favourite topic with science fiction writers is every kind of "anti-grav" screens. Alas, no such screens have been devised yet, and in order to overcome the force of the earth's gravitation a space vehicle requires a booster. Could gravitation and not an engine be used for the purpose?

A very extravagant question indeed, for is it not the earth's gravitation that does not let the vehicle vanish into space? Paradoxically enough, at least in one case such a way is possible. It was postulated by the Soviet researchers V. Beletsky and M. Giverts.

This is how they reasoned. In all the space navigation calculations the vehicle is taken for a material particle. This is quite logical: compared to the sizes of celestial bodies the size of the vehicle is infinitesimal.

But strictly speaking, the vehicle is not a particle. It is an extended body of definite dimensions and shape. The force of the earth's gravitation acting on it is in reality somewhat different from what it would be in case its whole mass should be concentrated in one point. True, with common space vehicles and satellites the difference is so small that it can be ignored safely.

There is one case where this difference may be important: when the spacecraft is of considerable length.

Let us examine the case of a craft consisting of two spheres connected with a rod or cable vertical to an extension of the earth's radius. In this case each of the spheres is influenced by the force of gravitation directed at an angle to the connecting rod. The resultant of these two forces is easily determined on the basis of the parallelogram law of forces. An elementary calculation produces a resultant which is somewhat smaller than the force of gravitation that would act on the centre of the rod should it concentrate the whole mass of this unusual craft. In other words, it seems that a "stretching" of the spaceship would amount to causing some sort of a repulsive radial force to be generated. This craft will revolve around the earth in an orbit slightly different from a regular Keplerian orbit.

An ingenious use could be made of this fact. Let us design our ship in such a way that it will be possible for us to bring the spheres together and to move them a big distance apart sufficiently fast.

Drawing the spheres close to each other when the craft is in the apogee, we practically reduce it to a material particle, whose further motion will proceed along a Keplerian orbit.

Let us perform the reverse operation—move the spheres apart to the former distance—when the vehicle is in the perigee. The repulsive force described above will then be produced. The orbit of the subsequent movement will become more elongated than the corresponding Keplerian orbit. The result will be that when the ship is in its second loop, the apogee distance will be a little greater than it was in the first loop.

Let us repeat the operation once more and the apogee distance will again become a little greater. If we continue the experiment, our vehicle will be spiralling outward until it escapes the bounds of the earth's gravitation.

But as we know, theoretical propositions do not always agree with the actual possibilities. Just how long will the boosting take if this method is applied?

According to V. Beletsky's calculations, if a 140-km ship is set in motion at a distance of 2 000 kilometres from the centre of the earth, acceleration will take something like two years.

A similar ship will need 80 years to break away from the sun's gravitation, given the initial distance of the ship from the sun is 700 000 kilometres.

One more paradox. The greater the mass of the celestial body and the closer the space vehicle to it, the easier it is for the latter to break through the chains of gravitation by means of the "pulse" method.

We often come across tragic situations in science fiction stories when a spaceship is trapped by the force of gravitation of some massive star. Beletsky's calculations show that even in the case of a ship moving around such a star escape velocity can be developed if the "pulse" method is used. For example, a ship situated 20 000 kilometres from the centre of the well-known superdense white dwarf, Sirius B, could escape into space along an unwinding path within a mere one hour and a half.

It is all very well on paper, but can a pulsating space vehicle be designed in reality? This is a problem for the technology of the future. In any case the theoretical possibility has been established in principle.

## A Strange Coincidence

Let us now consider one curious phenomenon typical of many members of the solar family. We know that the moon always shows us one and the same face. In something like 28 days it makes one revolution around the earth and one rotation on its own axis.

It is precisely the coincidence in the periods of rotation and revolution that explains why we invariably see the same side of the lunar sphere. But is it really a coincidence?

Generally speaking, nature is not so favourably disposed to such coincidences, and they indeed occur very rarely. This is only logical since this coincidence is too involved to be attributed to chance. And if we come across an amazing concurrence of events, it will most likely mean that there is a covered reason for it.

The moon's behaviour is not unique. Phenomena of this nature are also to be observed with regard to other bodies of the solar system. Mercury, the closest planet to the sun, completes one revolution around it in 88 terrestrial days and one rotation on its axis, in 59 days. No coincidence is apparent here at first glance. But according to Kepler's second law, the planets travel their elliptical orbits with variable speeds, and the closer to the sun, the higher the speed. If we calculate Mercury's angular velocities, we will see that they are the same for its revolution and rotation at the moment the planet is on the stretch of its orbit the closest to the sun.

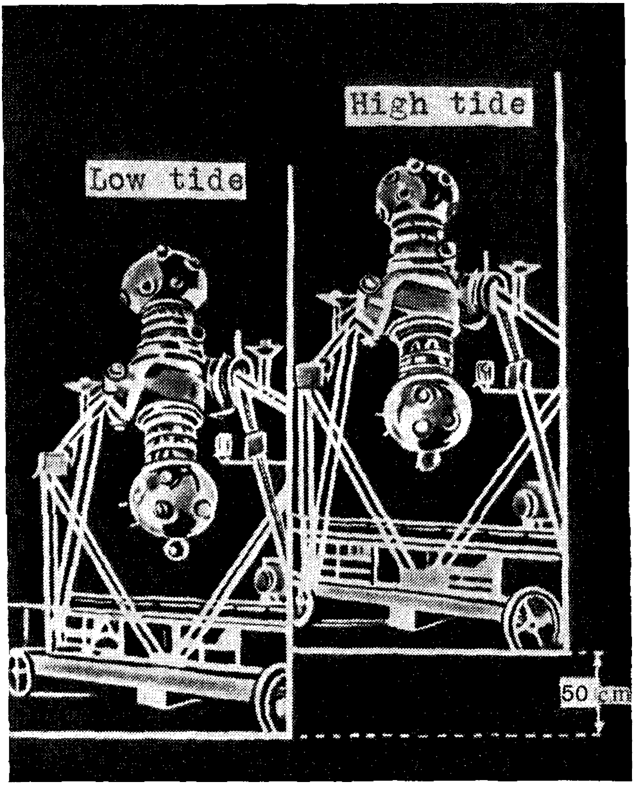
An even more complex coincidence characterizes the motion of Venus. As we know, Venus makes one revolution around the sun in 225 terrestrial days and every 584 days it appears on the line connecting the sun and the earth.

And at this moment Venus shows the earth one and the same face.

Is there a reason for these coincidences?

We all know about the tidal effects of the moon. The attraction of the moon causes two bulges to form on the earth's water surface. As the planet rotates, the bulges roll over the water surface in what we refer to as the tidal wave.

But tides also occur in solid matter. The high and low tides cause the ground to rise and fall something like 40-50 centimetres twice a day in Moscow. Since the tidal waves are in retrograde motion to the daily rotation of the earth, they are bound to slow it and rotation speed gradu-



Moon-tide effect in solid material in the region of Moscow

ally decreases. At one time in the past the terrestrial day was appreciably shorter than at present.

But if moon tides occur on the earth, then earth tides must happen on the moon, and this effect must be much greater too, since the mass of our planet is 81 times the moon's. Owing to this fact, the lunar rotation speed had to decelerate rather fast until its period reduced to become the same as the period of revolution. So now the moon is destined always to have only one face turned to the earth.

Apparently it was that same force that had equalled out the angular velocities of Mercury's rotation and revolution in the point of its orbit closest to the sun. The force of gravitation rapidly decreases in proportion to the square of distance, owing to which sun tides are far less conspicuous on the earth compared to moon tides. But in the case of Mercury, since it is the closest to the sun, these tides can be expected to be rather impressive, hence, appreciably to affect the planet's motion. And the equal angular velocities must also result from tidal deceleration.

As for Venus, it is still a mystery why it is always in the same position in relation to the earth when it is the closest to it. It is still to be found whether this phenomenon has a definite cause or is simply a coincidence. Probably the significant fact here is that the moment Venus is at the shortest distance to the earth, it is much closer to it than to the sun. But it still remains to be proved.

## Are We In for a Catastrophe?

We generally believe our solar system to be something reliable, something that we understand.

We know that it is ruled by one decisive force, the force of gravitation. The motion of each planet round the sun is governed by the Kepler's laws and takes place almost in one and the same plane for all the planets, except Pluto.

The actual reality is infinitely more complex. The point is that each of the planets is not only affected by solar gravitation but by the gravitation of all the other planets of the solar system, causing perturbations in the motion of every planet. The planet slightly deviates from its regular path charted by Kepler's laws, but then, invariably, recaptures it. Since the planetary positions in relation to one another are constantly changing, the general picture of their motion is extremely complicated.

The question which naturally arises is: can the disturbances in planetary motions lead to a catastrophe one day? Is there any guarantee that every time a planet slides off its space rails it will definitely return to its "native" orbit? What if the deviation proves too substantial? Cannot this swing, this peculiar vibration cause the solar system to collapse?

Computations alone can supply us an answer. To clarify the situation, it would be necessary to calculate the motion of every planet, most carefully considering all possible disturbances that may be caused by the influence of the other planets.

"To calculate" is easier said than done. Theoretically it is feasible, of course, if only with a measure of accuracy. The motion of celestial bodies is affected by gravitational forces, the value of which depends on the mass of the bodies and distances between them. The motion of any body, besides, is also determined by its velocity. It can be said, also with a margin of certainty, that the future of the contemporary system of celestial bodies is contained in the positions of these bodies in relation to one another, and in their velocities. The problem is, while accepting the mutual positions and speeds of the planets at the given moment as the point of departure, to compute their future displacements. From the standpoint of mathematics the problem is very difficult. The difficulty is that in any system consisting of space objects in motion there is constant redistribution of mass, owing to which the effect and direction of the forces acting on each body also change. And there is yet no conclusive general mathematical solution even for the simplest case of three interacting bodies.

It is possible to accomplish an accurate solution of this problem, known in celestial mechanics as the "problem of three bodies", only provided the case allows for certain simplifications.

Clearly, when we are dealing with nine interacting planets of the solar system in constant motion, even modern mathematics, for all its powerful computing techniques, cannot cope with the computation of their motions with absolute accuracy.

But is absolute acuracy so indispensable? In the final analysis, it is not so crucially important to know all the future positions of the planets so much as to obtain an answer to one single question: can planetary perturbations reach an unknown "critical borderline" beyond which a total and irreversible disintegration of the solar system will set in? In other words, we are interested in a qualitative rather than a quantitative solution to the problem.

There is a fundamental difference between the notions of "quantitative" and "qualitative". A quantitative solution demonstrates how much certain physical values change in relation to changes in others. A qualitative solution only gives an idea in what direction or within what limits the values we are interested in will change with the change in others.

Such knowledge is sufficient in many cases, for instance, in common stability problems. In the case of a chemical process, for instance to exclude the threat of an explosion, we should know the permissible deviations from the rated parameters. Another typical problem: it is necessary to compute a railway bridge in such a way that no oscillations originating from passing rolling stock can exceed the safety limit. There is no need to compute all the intermediate states of the system but it is enough to establish the connection between the changes in some of the initial and final values.

The problem of planetary perturbations is also a stability problem—stability of the solar system. And it allows for a qualitative solution.

Solution was supplied for the first time in history by the great Russian mathematician Alexander Lyapunov. He succeeded in demonstrating that in no conceivable situation the positions of the planets will be such that their mutual perturbations will be able to exceed the critical limit. We may hope, therefore, that no internal forces or interactions will ever impart enough "swing" to the solar system to bring it to the verge of collapse. The solar family is durable.

## The Sun and the Neutrino

As mentioned earlier, the sun is a "black box", in which astronomers can only observe the "outputs". All the knowledge of the sun available to modern astronomy is based on the study of the various radiations emitted from its outermost layers. No information comes directly from the solar depths. Strictly speaking, the theory of composition of the sun's interior proposing that its energy level is maintained by thermonuclear reactions is merely a theoretical model.

True, the word "merely" is not quite proper in this case. The thermonuclear theory does explain clearly enough processes of stellar evolution and is in good conformity with the observable physical characteristics of the sun and the stars. Nevertheless, just as any theoretical model of the inner arrangement of a "black box", this theory cannot be satisfactory, based as it is only on indirect evidence. Direct confirmation is essential and it should be derived from information coming directly from the interiors of the stars.

One way of obtaining such information has been outlined. It is by means of the so-called neutrino astronomy, or to be more exact, neutrino astrophysics.

Neutrino is the elusive particle directly involved in thermonuclear reactions. Thus neutrinos are formed in the thermonuclear transformation of hydrogen into helium, and, according to modern concepts, are a source of interstellar energy. The intensity of the flux of these particles and their energy depend on the temperature and nature of the thermonuclear reactions.

While the photon formed in the solar interior is affected by the impact of about 10 billion collisions before escaping into space, the penetrating capacity of the neutrino is such that it passes through the whole body of solar matter practically unobstructed and reaches the earth. Were it possible to "catch" it, we would be able to "see" what is going on in the solar interior. But this is an exceptionally difficult proposition as the neutrinos can be observed only indirectly, in interaction with other particles during thermonuclear reactions, the results of which can be registered.

One such reaction was suggested by the well-known physicist, Academician Bruno M. Pontecorvo, who pointed out that an isotope of chlorine, Cl-37, could capture a neutrino and be transformed into an isotope of argon, Ar-37, with the release of one electron, which was not difficult to register. Furthermore, since argon-37 was radioactive, its amount could be measured by the products of its decay.

The difficulty of registering the neutrinos by means of a chlorine detector is that it is necessary to isolate the neutrino flux from other cosmic radiations which can also start a nuclear reaction in which chlorine is transformed into argon. And this fact makes it necessary that all measurements should be made deep below the surface of the earth where other cosmic particles cannot penetrate.

The idea of a chlorine detector was implemented by the American physicist Raymond Davis and his colleagues. The neutrino trap was furnished by a huge tank filled with 600 tons of tetrachloroethylene, a common cleaning fluid, mounted in a rock cavity in the Homestake mine, near the town of Lead in South Dakota.

The results of observations which were carried out in several series over a lengthy period of time were puzzling—the number of chlorine transformations was much smaller than was predicted by theory.

Several hypotheses were advanced to explain the discrepancy between theory and practice. Among the more imaginative ones was the suggestion that the sun's thermonuclear furnace worked in cycles, or more exactly that owing to some peculiarities of the physical processes occurring in the sun's interior, the thermonuclear reaction stopped from time to time. During such periods solar radiation was fuelled by the energy stored up during the previous cycle.

It will be recalled that the electromagnetic radiation coming to us from the sun was actually emitted about a million years ago—it had to cover the distance from the sun's interior to its surface and then to the surface of the earth. But as far as the neutrinos are concerned, they "report" on the state of the sun practically at the moment of observation. Small wonder, therefore, that the electromagnetic and neutrino "pictures" may differ from each other. Could the absence of solar neutrinos in Davis's experiment be interpreted as an indication that in our epoch the sun's thermonuclear furnace is idling?

To answer this question further neutrino experiments are obviously essential, and facilities for such experiments are being developed right now.

Another thing which could probably explain the results of Davis's observations is the nature of the neutrino itself. We will return to this subject in the next chapter.

# Chapter 3

# Deep in the Universe

## The Universe

On moonless nights we get a clear view of the nebulous strip of the Milky Way. This is our Galaxy and it consists not of clusters of nebula but of numerous stars, some 200 billions of them, according to modern estimates. Travelling at a speed of 300 000 kilometres per second, a ray of light will pass its length in about 100 000 years.

Despite its stupendous size, the Galaxy is only one among numerous starry islands in the universe. It has companions and the biggest of them are the Large and Small Magellanic Clouds. Together with the Galaxy they rotate around a common centre of mass. The Galaxy, the Magellanic Clouds together with several other star systems, including the Andromeda nebula, are referred to as the local group of galaxies.

Modern telescopes and radiotelescopes, as well as other means of astronomic observations, cover a colossal area. Its radius is 10 to 12 billion light-years. This area houses billions of galaxies which form the Metagalaxy.

In the study of the infinitely diverse material world science distinguishes objects, phenomena, connections and interactions. On a larger scale, it also sets apart notions of the astronomic universe from those of the entire material world.

Academician Pyotr Fedoseyev, a leading Soviet philosopher, writes:

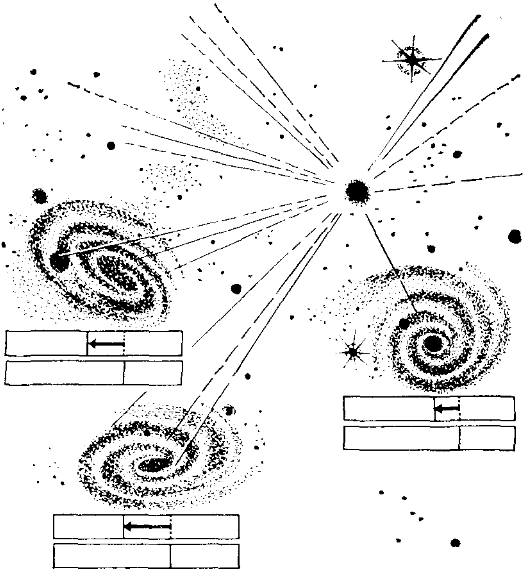
"... From the standpoint of the principle of evolution there is every reason to believe that the universe being studied by modern natural sciences is an entity developing in time, an entity which originated from some preceding states and forms of matter and which will be replaced by some new states and forms.

A materialist philosophy does not recognize the idea of creation of the physical world by consciousness, by a supreme being. If we agree that the universe being studied today originated 20 billion years ago, then it is important, from a philosophical point of view, to acknowledge the objective nature of this process as a cosmic stage in the self-evolution of matter. It is the task of concrete science to understand and describe this process in physical terms. It is possible to conceive of the existence of many universes with a complex topology. It is sensible therefore, to distinguish between the notion of the universe of the natural scientist, which defines the knowledge we have amassed by now, and the philosophical notion of the material world, which includes in a concealed form all the future achievements of natural sciences in their study of the universe".

## In an Expanding Metagalaxy

It will be no exaggeration to say that the theory of the expanding universe or Metagalaxy is one of the most fascinating ones postulated in this century.

It is based on the idea that the Metagalaxy emerged about 15 to 20 billion years ago as a



Scheme of an expanding Metagalaxy. Red spectral shift increases with distance

result of a great cosmic explosion of a clot of superdense matter.

A few words on how this theory originated.

The elaboration of theoretical models, or simplified theoretical schemes of the universe, is one of the most effective methods of study of its structure. For a long time cosmology concerned itself with uniform isotropic models. What are they?

Let us imagine that the universe has been divided into numerous "elementary" areas, each containing a large number of galaxies. In this case homogeneity and isotropy mean that the properties and behaviour of the universe are the same for all areas and in all directions in every epoch.

Einstein elaborated the first model of a homogeneous isotropic universe. It was the theory of a stationary universe that remains unchanged in its general characteristics with the passage of time, and registers absolutely no motions of any large scale. It is a universe governed by uniform laws of nature which can be expressed in mathematical equations.

In 1922, A. Fridman, a distinguished Leningrad scientist, demonstrated that Einstein's equations permit of numerous models that are not stationary, that is, expanding and contracting, homogeneous and isotropic. It was later found that Einstein's static model, too, was bound to transform into one that was not static.

That meant that a homogeneous isotropic universe should either be expanding or contracting.

Prior to that, the American astronomer Slipher detected a red shift in the lines of galactic spectra. This phenomenon, known in physics as the Doppler effect, is observed when the distance between the source of light and the observer is increasing. Consequently, it had to be assumed that the distant galaxies, or sources of light observed from the earth, are drawing farther away from our planet.

Following Fridman's work another American astronomer, Edwin Hubble, proved conclusively that the farther a galaxy is situated from us, the greater the red displacement in its spectrum, It was also established that the shift was almost directly proportional to distance. From the point of view of the Doppler effect, this means that the remote galaxies are receding from the earth and from each other and that the farther any one of them, the faster its recession rate.

*It was on the basis of this scheme explaining* the motion of galaxies by means of the Doppler effect that the theory of an expanding Metagalaxy was elaborated.

However, this view was not universally accepted. At different times attempts to explain the red shift by causes other than the recession of galaxies were made. But none was satisfactory.

Similar attempts are made now too.

Let us try to establish if it is possible to decipher the red shift in galactic spectra not by the Doppler effect but by some other reason, and to see if there are serious grounds to question the theory of the expanding Metagalaxy.

A widely discussed counter-argument deals with the "ageing" of the photons, their gradual "degeneration" and their decreasing energies (i.e., increasing wavelengths) occurring during their long journey through space.

The "dispute" between the Doppler effect and the effect of degeneration can be settled conclusively enough by way of astronomic observations. The point is that strictly speaking these two effects are not quite similar.

As calculations show, with the ageing of photons the change Δν of the frequency ν (that is, the shift in the spectral lines) must be the same for the whole spectrum; in other words, *the value of the shift does not depend on frequency.*

*In the case of the Doppler effect the change in frequency is proportional to frequency.* The constant here is not the value of the change Δν but its ratio to the respective frequency Δν/ν. In other words, the value of the shift in this case is not the same for the different lines of the spectrum.

Meanwhile observations show that the red shift in galactic spectra is such that for the various lines of one and the same spectrum the constant is not the change in frequency but exactly the ratio of this change to the frequency itself. And this seems to be a weighty argument in favour of the Doppler effect as an explanation.

Now to the question of "degeneration" of the photons. If the shift in the spectral lines does not depend on frequency, then it must be more pronounced in the comparatively *low frequency* range, that is, in the radio wavelengths. Here like on a "stretched" dial of a wireless set any change in frequency, however small, will be noticed immediately. But astrophysical observations have revealed nothing like that yet.

It must be noticed for the sake of justice that in principle another physical phenomenon, also characterized by properties similar to the Doppler effect, is possible. When radiation propagates in a gravitational field, its frequency changes in the same way as in the case of the mutual recession of the source of radiation and the observer. However, it has been proved by calculations that in the case of the distant galaxies the "gravitational shift" or the Einstein effect only constitutes an addition to the Doppler effect.

To sum up. Modern physics knows nothing

except the Doppler effect that can explain the red shift in galactic spectra.

Are there really any serious grounds to look for other interpretations? Such a search would be justified if the Doppler hypothesis led to any serious discrepancies. Have any been discovered?

One of the counter-arguments advanced some time in the past was based on the age of space objects. According to the theory of the expanding Metagalaxy, the expansion era has lasted for about 10 to 20 billion years. Does this view agree with the established age of the stars, star clusters and galaxies?

It really seemed at one time that the estimated duration of the era of expansion did not accord well with the age of space objects. But the generally accepted view today is that the age of all the known space objects is of the order of 10 billion years.

Still estimates of 20 and more billion years have been made. The question is, then, that if these estimates are confirmed, will the expansion theory be refuted?

A. Zelmanov stresses that the conclusion about the era of expansion having lasted 10 to 20 billion years was based on the theory of a uniform isotropic universe and that if the problem was approached from the standpoint of a more general theory, this age could conceivably be extended.

It must be noted, that the theory of a uniform isotropic universe itself allows for modifications under which the duration of the expansion era can be enlarged. Most of the versions of this theory suggest that at the initial stages of the expansion, the mutual gravitational attraction of masses prevails and acts as a brake on the expansion process. But as expansion continues, the gravitational attraction decreases while the repulsion of space objects, which is allowed for under certain conditions by the equations of the general theory of relativity, sets in. There may well be a point where the attraction is balanced by repulsion, then gives way to it and finally, decelerated expansion becomes accelerated.

Let us suppose that such was really the case with the Metagalaxy and we are now going through an age of accelerated expansion. But then we can also assume that in some recent past the process was slower, hence lasted for a longer period than it would under the continuous action of braking.

On the other hand, the universe can likewise be assumed to be younger.

According to the theory of a hot expanding universe, the beginning of the expansion was in a while to be followed by a stage when all matter would be in plasma state consisting of electrons, protons and nuclei of light elements. Apart from matter there would also be electromagnetic radiation: radio waves, light and X-rays. At that period matter and radiation would be in equilibrium. The particles (mainly electrons) would be radiating about the same amount of photons as they would be absorbing.

But then the temperature would drop so much that electrons would begin to combine with ions producing atoms of hydrogen, helium and other elements. Space would become transparent to radiation, the photons would practically cease to be radiated or absorbed.

Subsequently, the temperature of the radiation would gradually drop and, as computations of the theory of the hot expanding universe indicate, space at our age would be permeated with a radiation having a temperature of about 3 or 4 K.

In 1965, this residual radiation was indeed registered and called 3-degree background radiation. It confirmed that the expansion of the universe had been going on for billions of years and that it had started out from a density of about billions of times greater than the present density of the universe.

But in the years that followed this conclusion began to be questioned. Some scientists considered that it was not residual radiation which had been registered but a certain general heat background of an entirely different physical nature.

There was also a theory interpreting the radiation not as residual but as having originated in some remote past in individual space objects and having been subsequently scattered over the universe.

But the congress of the International Astronomic Union of 1970 in London unanimously agreed that at present there were really no serious grounds to question the primordial origin of the registered background radiation.

As to the theory that this radiation had originated in individual sources, were that the case, we should now be able to observe fluctuations in the radio emission in places where these sources had once been situated. But as was convincingly demonstrated by the work of Yu. Pariysky of the Soviet Union, no such fluctuations have been detected anywhere.

It must be emphasized, that even if it is found that no residual radiation has ever existed, it will not at all mean that the expansion theory must be given up. This theory allows for a situation where no such radiation emerges.

The study of the quasars supplies a very important argument in support of the expansion theory. In the areas of the universe that are relatively close to us the spatial density of quasars is comparatively small. But at a distance of the order of 7-9 billion light years it increases considerably to fall, at some point, back to zero. This means that in a remote past the density of the quasars was greater, and that still earlier there had been no quasars at all yet.

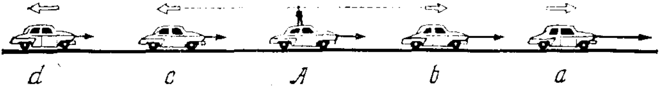
Thus the quasars bear independent proof of the fact that the universe is not stationary. At the same time doubts have been expressed about whether we really possess the essential standards to measure the red shift. For if the wavelengths of the electromagnetic radiation increase in the same manner as metagalactic distances, and the dimensions of the atoms, along with the wavelengths, then nothing can really be detected.

But it must be underlined that according to modern physical postulates, the expansion of the Metagalaxy causes a change only on a cosmological scale, but not on microscopic and macroscopic scales. This is not a point of view but a question intimately related with the fundamentals of modern physics.

## Are We in the Centre?

Thus, we live in an expanding Metagalaxy and observe galaxies scattering in all directions. We may be under the impression that it is we that are in the centre of the expansion, that we are in a static point of the universe from which all the other stellar worlds are receding. But this impression does not very well agree with the theory of probability and is bewildering: why we?

Indeed the impression that we are in the centre of the Metagalaxy is fallacious. The following example of A. Zelmanov illustrates how this impression is created. Let us imagine that a large number of cars starts from one place on an absolutely straight highway and begins moving in the same direction, every car at different speed. In a while they will obviously occupy definite positions in relation to each other, according to their speeds—those that are going faster will be ahead and the slower ones will fall behind.



Analogy explaining the absence of a centre of an expanding Metagalaxy

Now it is obvious that every car riding ahead will be moving at a higher speed than the one behind. The observer is in one of the cars in the middle of the line and can see the rest of the cars ahead and behind. No matter which car he is in, it will seem to him that he is in the centre of the stretching line of cars since all the other cars, both ahead and behind, will be receding from him: those ahead will get farther and farther away and those behind will become more and more remote.

It is the same with the red shift in the Metagalaxy. It only demonstrates the growing distances between us and the other galaxies, and the distances between those galaxies themselves. But it does not mean that we are in the centre. If we move to some other galaxy, we will again feel that it is the central one.

One more question has to be clarified in connection with the expansion of the Metagalaxy. We know that the distance to a galaxy is determined on the basis of the Hubble law: the greater the red shift, the farther the galaxy is from us. But during the time it took the light emitted by the galaxy to reach us this galaxy had to recede to an even greater distance. Moreover, we receive simultaneously light coming from different galaxies and emitted in different epochs. Does this not completely confuse the picture of the Metagalaxy?

Our misgivings are groundless because it does not. The theory takes account of these facts and is evolved in such a way that all the distances are automatically recalculated and brought in line with one and the same epoch, the epoch of observation.

Another question arises: why does the red shift increase with distance, that is, why do the more remote galaxies recede at greater speeds? The dependence of the red shift on the distance is not the result of ejection of galaxies from some primal point with different speeds. The expansion of the Metagalaxy proceeds in such a way that the increase in the rate of recession between any two points is proportional to the distance between them. This postulate was proved by observations as far back as 1929.

## A Mysterious Background

When we observe the universe in visible light we see stars, galaxies and galactic clusters, all grouped in strictly delineated structures. An infrared, ultraviolet and radio "view" of the celestial sphere broadens our optical picture of the universe dramatically. In other words, all these types of electromagnetic radiation are an important source of scientific information about the objects emitting them. We cannot say the same thing about the 3-degree background radiation mentioned earlier and about the background X-ray radiation discovered in the 1960s.

Just like the residual background radiation, the X-ray radiation fills all space in all directions and is highly isotropic. It could be supposed that the two isotropic constituents of the universe are somehow interconnected, were it not for the fact that they are caused by totally different physical processes.

As to the origin of the residual radiation, it has been studied fairly well by now. The origin of the X-ray background is still a mystery.

The easiest thing would be to assume that the X-ray background, which also has a diffuse component, is caused by the bremsstrahlung ("brake radiation") of the electrons in plasma filling intergalactic space. But the difficulty here is that there is no evidence to prove the existence of plasma. If such evidence could be provided, we would have to make new fundamental conclusions concerning the future evolution of the universe.

It has been found that if the hypothetic intergalactic plasma is responsible for the actually observed X-ray radiation it should be characterized by near-critical density, i.e. the mean density of matter in the universe which, according to the general theory of relativity, should be enough to stop the scattering of galaxies.

If the source of radiation is not known a study of its properties is our best hope to find some clues about it. As has been pointed out, the X-ray radiation is highly isotropic—the most sophisticated X-ray *detectors have failed to register* any changes in its intensity.

What does the isotropy indicate in this case? Either that the radiation source is in the immediate vicinity of the earth and therefore the latter is situated "inside" it, or that it is very far. The second possibility is more likely because obviously we must rule out the presence of any powerful X sources in the environs of the solar system.

On the other hand we should remember that the greater the distance a given radiation has travelled before reaching the earth the earlier events of history it "reports". This means that there is every reason to assume that the origin of the X-ray radiation (just as the residual background radiation) should be attributed to some large-scale cosmological events.

Some astrophysicists think that this radiation originates in a large number of sufficiently powerful discrete sources, more or less evenly distributed over the celestial sphere and situated great distances away from earth.

What could these sources be? Not galaxies. Galaxies consist of stars and as the study of the sun has shown, ordinary, "normal" stars are very weak sources of X-rays. Even the hundreds of billions of stars making up the galaxies could not account for the intensity of the X-radiation being observed. During the last few years, it is true, it has been established that abundant galactic clusters rich in stars do emit X-rays owing to the bremsstrahlung in the plasma filling intergalactic space in such clusters.

And yet, considering the concentration of galactic clusters in the universe, even this source is plainly inadequate. So, the galaxies must be excluded.

Quasars seem to be the best answer to our question. Observations have proved most of them to be powerful X sources: one quasar emits 1 000 times more energy in the X-ray region than all the stars in our Galaxy in the visible region.

Quasars are very remote objects, some of them being situated at distances even greater than the remotest galaxies. That is why most of them are outside the reach of modern observational facilities. But statistical calculations based on the distribution of known quasars in space indicate that a substantial proportion of the X-ray background (and probably all of it) is generated by these far objects.

## The Universe in Gamma-Rays

Astronomy was a purely optical science for a long time. The subject of its study was everything that could be seen in the sky, first by the unaided eye and then through telescopes. The development of radio techniques gave rise to radioastronomy. Equipped as it is with means of space exploration, present-day astronomy is able to reach beyond the confines of the atmosphere and extend its knowledge of the universe by studying infrared, ultraviolet, X- and gamma-ray radiations. It can now be described as a science working in all wavelengths.

Although fairly young, X-ray astronomy has made an invaluable contribution to our image of the universe. But probably even more informative is gamma-ray astronomy, i.e. the study of gamma rays in space. The energy of gamma quanta may be hundreds, thousands or even millions of times greater than the energy of the photons of visible light. The universe is in fact transparent to gamma rays. Travelling in straight lines from extremely remote objects, these rays carry a wealth of information about physical processes developing in space.

What is of special importance is that gamma radiation may "report" on extreme states of matter, a subject of the greatest interest to astrophysicists. It originates in areas of encounter of matter and anti-matter, and accompanies the formation of cosmic rays—fluxes of energetic particles.

The main difficulty of gamma astronomy is the fact that although the energy of gamma quanta is enormous, their number in near space is infinitesimal. Gamma telescopes register one gamma quantum in a few minutes even in cases of the "brightest" gamma sources.

Another difficulty is that the radiation is received against a background of disturbances. Under the action of electrons and protons—the charged particles of the cosmic rays coming to earth—the earth's atmosphere and the spacecraft carrying registering devices, begin to "shine" in gamma "light".

What picture of the sky would we get if our eyes were sensitive to gamma-quanta and not light waves? We would not see the sun or any of the familiar constellations, and the Milky Way would look like a narrow strip of luminosity. This distribution of gamma radiation, among other things, confirms the theory of the well-known Soviet physicist, Academician Vitali Ginzburg, that cosmic rays are mainly of galactic and not extragalactic origin.

Several dozen sources of cosmic gamma radiation have been detected by means of gamma telescopes mounted on space vehicles. So far it has been impossible to say with certainty if they are stars or other compact bodies or extended objects. There is reason to suppose that gamma-radiation originates from unstationary, violent events, such as supernova explosions. But evidence in support of this theory is slim: a study of 88 known supernova remnants has revealed only two gamma sources.

At the same time extragalactic gamma sources have been registered. They are connected with active galaxies and quasars characterized by explosive events which are tens of millions of times more powerful than supernova explosions. It is quite likely that astronomy is on the eve of discovering a space object of a fundamentally new class.

A gamma source has been discovered in the constellation Ophiuchus. This is a nebula in the centre of which there is a dense cloud of gas and dust harbouring a group of young and very hot stars. Another gamma source was detected in the Orion nebula in which associations of young stars, according to some observers, are expanding.

It has been assumed that supernova explosions signify one of the concluding stages in stellar life. At the same time violent events also accompany the earliest stages in stellar evolution. It can probably be supposed that gamma radiation and the violent events giving rise to it may be associated not with the death but the birth of stars.

In principle high-energy cosmic gamma radiation makes it possible to detect objects that generate cosmic rays, a fact the significance of which cannot be exaggerated: astrophysicists have long been trying to establish the mechanism whereby cosmic radiation is produced. Theorists reason that when energetic nuclei contained in cosmic rays interact with the gas and dust particles of the interstellar medium surrounding their source a special kind of elementary particle—neutral pi meson—must be released. These particles are unstable and soon decay into gamma-quanta which can be registered by gamma telescopes. The gamma flux is the more intense the greater the density of cosmic radiation. Gamma observations, therefore, enable astronomers to determine both the spot where the object generating cosmic rays is situated and its intensity.

Neutron stars or pulsars are also sources of gamma radiation. The brightest pulsar which cannot be registered by optical telescopes is located in the constellation Vela. Another one is associated with the Crab Nebula. No direct evidence has been obtained, however, to link the energetic nuclei with the pulsars and so to demonstrate that the pulsars are the primary sources of cosmic rays. Most likely gamma radiation is caused by fast electrons of a secondary origin i.e. as a result of the collisions between the nuclei of the cosmic rays and those of the interstellar gas.

A few years ago instruments mounted on artificial earth satellites and high-altitude observation balloons registered powerful bursts of cosmic gamma radiation. The energy released during the bursts was something like a million times greater than the energy of visible solar radiation.

The physical nature of these phenomena is still obscure but there is reason to suppose that they may be connected with events developing in binary star systems which include neutron stars. One likelihood is that the gamma bursts were caused by matter being ejected by one of the stars in the binary and falling onto its neutron companion.

To sum up. The study of cosmic gamma radiation is expected to answer questions that are of crucial importance to our understanding of the structure of space objects and of events occurring in the universe. The fact that gamma quanta propagate in straight lines should make it easier not only to detect remote gamma sources but also to trace the directions in which they are situated. On the other hand, being caused by the action of fast or nonthermal particles, gamma radiation also carries information about phenomena associated with high concentrations of such particles.

## Explosions in Space

Until thirty or forty years ago astronomers believed that space objects did not change much with time and that stars and galaxies developed so slowly that no significant evolution could occur in them within observable spans of time. True, they knew about variable stars distinguished by frequent changes in brightness, about stars that were ejecting matter in violent processes, and about nova and supernova explosions accompanied by the release of enormous amounts of energy. All these phenomena attracted the liveliest scientific interest, but were believed to be episodic and of no major importance.

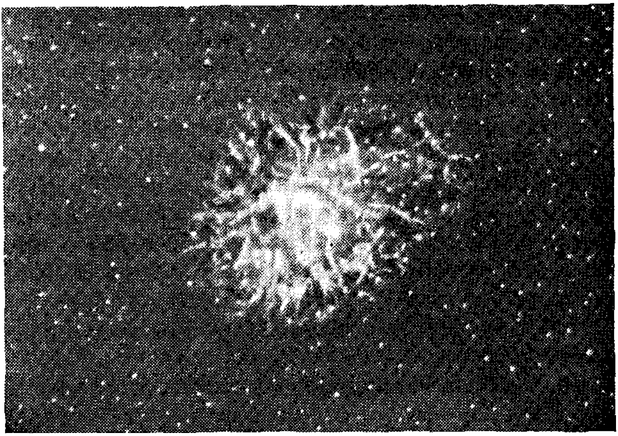
In the 1950s, however, this view was replaced by the general conviction that nonstationary phenomena were natural stages in the evolution of matter in the universe playing a crucial role in the life of space objects. A whole class of violent and even explosive events characterized by colossal energy outputs were discovered. It was found, in particular, that some galaxies were sources of powerful radio emission.

One of them is the radio galaxy Cygnus A in the region of the constellation Cygnus. This is an extraordinarily powerful radiostation: its emission is received on earth and is equal to the energy of the sun's rest mass, although the distance to the sun is only about eight light-minutes and to the galaxy in Cygnus, about 700 million light-years.

It has been established that the total energy output of relativistic electrons, i.e. electrons propagating at a speed comparable to the velocity of light, which induce the radio emission of radio galaxies, may be enormous. The Cygnus A radio source, for instance, emits energy tens of times greater than the gravitational energy of all the stars in this galaxy and hundreds of times greater than its rotational energy.

Two questions arise in this connection: what is the physical mechanism of the radio emission of radiogalaxies and what is the source of the energy maintaining it?

A small gaseous nebulosity in the constellation Taurus situated in the northern celestial hemisphere has long excited the minds of astronomers. For its curious shape resembling a huge crab with numerous tentacles they called it the Crab Nebula. A comparative analysis of its photographs made in different years showed that its composite gases were being ejected at the colossal speed of about 1 000 kilometres per second. It was assumed that was the result of a tremendous explosion which occurred something like 900 years ago when all matter in the nebula was concentrated in one point. What happened in



The Crab Nebula

that region at the beginning of the second millenium AD?

The chronicles of those times relate that a star flared up in the constellation Taurus in the spring of 1054. It was shining so brightly for 23 days that people could plainly see it in broad daylight. Scientists arrived at the conclusion that the Crab Nebula was a remnant of a supernova explosion.

Further observations showed that the Crab Nebula was an uncommonly powerful source of radio emission. It will be recalled that any space object—a galaxy, star, planet or nebula—must radiate electromagnetic waves (thermal radio emission) in the radio band if its temperature is above absolute zero. The amazing fact about the

Crab Nebula was that its radio emission was much more powerful than the value of the thermal radio emission it should have had in conformity with its temperature. It was then one of the most outstanding theories was developed which not only explained the nature of the radio emission of the Crab Nebula but also gave a clue to understanding very many events occurring in the universe. That was only natural since every single space object reflects the general laws of natural processes.

That was the theory of nonthermal electromagnetic radiation of space objects induced by relativistic electrons in magnetic fields, worked out primarily by Soviet scientists. It was termed synchrotron radiation by analogy with processes developing in accelerators of charged particles.

It was further established that the synchrotron radiation characterized a whole range of space events. In particular, it was found that the radio emission of radio galaxies was of synchrotron origin.

As to the sources of energy, in the Crab Nebula that source was a supernova explosion. And what about the radio galaxies?

There are many facts on the basis of which it can probably be assumed that the energy source maintaining radio emission is furnished by the active physical processes taking place in the cores of these galaxies.

The cores of galaxies are compact structures in the central regions of most of the known galaxies which have strong magnetic fields. Often the core of a galaxy is responsible for a considerable proportion of the radiation of the whole of the galaxy. There is a core in our Galaxy as well. As radio observations have shown, there is a constant outflow of hydrogen from it. In a year it discharges an amount of gas equal to one and a half solar masses. This is not so much at first sight. But considering the fact that our Galaxy is over ten billion years old, the amount of discharged matter is truly staggering. Furthermore there is every reason to suppose that the process being registered today is only a weak echo of much more turbulent events which took place in the core of our Galaxy when it was younger and richer in energy. This is confirmed by the very active phenomena being observed in the cores of some other galaxies.

The galaxy M 82, for instance, displays a scattering of gas jets in all directions at a speed of up to 1 500 kilometres per second. It is assumed that this is a result of an explosion in the core of this galaxy several million years ago. According to some estimates, the energy of the explosion was comparable to the energy of a thermonuclear explosion with a mass equal to several tens of thousands of solar masses. Although the explosion in M 82 has lately been called into question, there are several other galaxies whose cores exhibit violent nonstationary events.

In 1963 extraordinary objects were discovered at great distances from our Galaxy. They were called quasi stellar radio sources or quasars. They are incomparably smaller than the galaxies, those huge stellar islands of the universe, but each quasar emits hundreds of times more energy than the greatest galaxies harbouring hundreds of billions of stars.

The discovery of the quasars was quite unexpected. It was one of those incredible surprises which the infinitely varied universe has produced and will yet produce. Physicists and astrophysicists could never predict the existence of such objects. In the words of the well-known Soviet astrophysicist I. D. Novikov, if the properties of quasars were described to them beforehand, they would definitely have declared that such objects could never exist in nature.

But they do exist and their physical nature demands explanation. So far no definite conclusion has been made. Various theories have been advanced and rejected and some are still under consideration.

Whereas it has not been found what physical processes may lead to the generation of such great amounts of energy, considerable progress has been made in establishing in what range of space objects should the quasars be included, whether they are unique formations falling out of the general rules or are a natural stage in the evolution of space systems.

This line of research is typical of contemporary astrophysics. It was not so long ago when astronomers were mainly interested in studying the physical properties of a space object. Today they concentrate on the history of this object, on its earlier stages and on the laws explaining its origin and evolution. This approach comes as a result of our awareness of the fact that we are living in an expanding, nonstationary universe, whose past is different from its present and whose present is different from its future.

In the light of these ideas astronomers have found it especially interesting to try to establish any possible intrinsic connections between non-stationary objects in space. One of their discoveries is the fact that in their structure and optical properties radio galaxies are nothing extraordinary. Any radio galaxy conforms to a "normal" one which is different from the first only by its radio emission. Since this is so it can probably be assumed that a galaxy begins to emit intense radiation in radio frequencies at a definite stage of its evolution, that this is a peculiar sign of a definite age in the life of some types of galaxies, and that these galaxies later lose this ability. This theory seems to be supported by the fact that radio galaxies are far fewer than "normal" ones.

Could it then be supposed that the quasars, being the powerful "energy plants" that they are, are also a definite stage in the evolution of space objects, perhaps one of the earliest stages? An analysis of electromagnetic radiation of quasars reveals a clear resemblance between them and the cores of some types of radio galaxies.

A prominent Moscow astronomer, B. A. Vorontsov-Velyaminov, has pointed out one curious fact: almost all the known quasars (more than one and a half thousand in all) are single objects while the radio galaxies closely resembling the quasars form as a rule the central, brightest and most active parts of clusters of galaxies. His theory is that the quasars are "protoclusters" of galaxies whose evolution had led to the formation of galaxies and clusters of galaxies.

Important evidence in favour of Vorontsov-Velyaminov's hypothesis is the activity of galactic cores which is very much in the nature of the activity of quasars even though it is not so violent. Particularly turbulent activity is to be observed in the Seyfert galaxies, whose cores, although far smaller than the quasars, are extremely powerful sources of electromagnetic radiation. The movement of gas within them reaches the fantastic speed of several thousand kilometres per second. Many Seyfert galaxies eject dense gas clouds with masses equal to tens and hundreds of solar masses. This process is accompanied by colossal energy outputs. A good example is the Seyfert galaxy NGC 1275 (radio source Perseus A). Some five million years ago (by the time scale of this galaxy) it was the scene of a violent explosion with a discharge of gas jets at a speed of up to 3 000 kilometres per second which is by two orders faster than the dispersal of gas in the M 82 galaxy.

Another type of galaxy with an active core was discovered by B. Ye. Markaryan of the Soviet Union. The core in this galaxy is an abnormally powerful source of ultraviolet radiation. Apparently the galaxies of this type are now living through an epoch following the explosive discharge of matter, that is, a posteruptive epoch.

It may well be that the radiation energy of quasars and cores of galaxies originates from similar physical processes. The quasars, it will be recalled, are very far objects. The farther a space object is from the earth, the earlier stage in its evolution we are observing. The galaxies, including those with active cores, are on the whole situated closer to our planet than the quasars. It is logical to suppose, therefore, that they are objects which must have formed later than the quasars. Obviously this is a significant fact in support of the hypothesis that quasars are probably the cores of future galaxies.

As to the nature of the physical processes inducing the great power output, one fascinating hypothesis merits special consideration.

## Black Holes in the Universe

The "black hole" hypothesis stands out among even the most intriguing recent developments in theoretical astrophysics.

The 20th century has been a time when extraordinary discoveries in physics and astronomy have invariably led to further discoveries that were even more extraordinary, marking yet another stage in the development of natural science.

But in the interest they have aroused few of them can be compared with the still hypothetical black holes. The idea sounds incredible: holes in space and black holes at that!

According to Einstein's general theory of relativity gravitational forces are the property of space. A body in space does not simply exist but determines the geometry of the space around it. Once a journalist interviewing Einstein asked him to explain his theory in one phrase and so that the general public could understand it. Einstein replied that it had always been believed that if all matter should disappear from the universe, then time and space would remain, while the theory of relativity asserted that time and space would disappear together with matter.

Mass is therefore related to space. Any mass causes the surrounding space to curve. We hardly notice any such curvature in our daily lives because we generally deal with comparatively small masses. But in very strong gravitational fields the curvature may acquire a substantial value.

Several events recently observed in space indicate the possibility of enormous mass concentrations in small areas of space. If matter of a certain mass is squeezed into a small volume critical for this mass this matter will begin to contract under the effect of its own gravitation. As it contracts further, gravitational catastrophe develops and what is termed gravitational collapse sets in. Concentration of mass grows in the process; the curvature of space also becomes more and more pronounced in conformity with the theory of relativity. Finally the moment arrives beginning from which not a single ray of light, not a particle and not a single other physical signal can escape from this area of collapsed mass. This is what has become known as a black hole.

For an outside observer such an object ceases to exist, as it were: no information can be received from it since for information to propagate it needs a material vehicle.

The radius of a collapsing object becoming a black hole is referred to as gravitational. For the mass of the sun this radius is three kilometres and for the mass of the earth, 0.9 centimetre. Were the sun to contract into a ball with a radius of three kilometres it would become a black hole.

Gravitation is infinitely strong at the surface of a body whose radius equals the gravitational radius for its mass. In order to overcome it it would be necessary to develop escape velocity which would be greater than the velocity of light. According to the now accepted special theory of relativity nothing in the universe can move at a velocity greater than the velocity of light. This is why a black hole lets nothing escape from it. On the other hand, it can suck in matter from surrounding space and grow in size. But it needs the general theory of relativity to describe all phenomena associated with the black holes. This theory postulates that time slows down in a strong gravitational field. For an outside observer the falling of a body into the black hole must take infinitely long and as matter approaches the gravitational radius the process of contraction actually stops. An imaginary observer falling into the black hole together with matter would see an entirely different picture. Having reached the gravitational radius within a finite period of time, he would continue falling to the centre of the black hole. Collapsing matter would continue contracting after passing the gravitational radius.

According to modern theoretical astrophysics black holes may be the concluding stage in the life of massive stars. As long as an energy source functions in the central region of the star high temperatures cause gas to expand and move apart the layers above it. At the same time the colossal gravitational force of the star is drawing these layers back to the centre. After the fuel powering the nuclear reactions becomes exhausted the temperature in its central region gradually begins to drop. Instability sets in and the star begins to contract under the force of its own gravitation. Its further evolution depends on its mass. According to calculations, if the star's mass is three to five suns, the concluding stage of its contraction may result in gravitational collapse and the formation of a black hole.

Several years ago an object that could be a black hole was discovered in Cygnus. It is a dark object with a mass equal to 14 solar masses but it is still to be proved if it really is a black hole.

It has been suggested more and more often lately that the cores of galaxies and quasars may harbour supermassive black holes which account for the activity of these space objects. Such black holes are said to be able to suck in ambient matter whose kinetic energy in the gravitational field may be converted to other forms of energy. An interesting discovery was made in the M 87 galaxy (Virgo A radio source). A photograph of this galaxy clearly shows a jet coming from the core. The jet consists of several discrete gas blobs averaging a mass of 10 million solar masses and moving with a velocity of the order of 3 000 kilometres per second. Thus the core must have experienced a powerful detonation.

Astronomers have established that if the distribution of matter in M 87 at some distance from the core agrees with the general distribution of stars in galaxies, then a colossal dim mass equalling six billion suns is concentrated in a small volume close to the galaxy's centre. It is probable that this is a gigantic black hole inducing the activity of the core, or a very dense structure yet unknown to science.

## From Star to Star

Since double-star systems constitute a substantial part of the star population of the universe they merit special attention. Until the study of space objects was confined to observations in the optical and radio bands our knowledge of these systems consisted mainly of the purely mechanical processes occurring in them. A "glimpse" into the X and gamma regions revealed to astronomers that some of the binary systems are scenes of unusual and hitherto unknown physical phenomena. In such systems one of the stars is "normal" and its companion may be a neutron star or a black hole.

Neutron stars are extraordinary objects. They are not more than 20 kilometres in diameter, have a mass of a million solar masses and a fantastic density of 100 million tons per cubic centimetre. That is why hot gas being expelled by the normal star and hitting the neutron star is accelerated to a speed of up to 100 000 kilometres per second. The interaction between the expelled matter and the neutron star results in the appearance of hot spots on its surface which have a temperature of millions of degrees. At this temperature X-ray radiation is induced. Since the neutron star is rotating rapidly, an observer stationed on earth sees these hot radiating spots only at certain time intervals. The phenomenon has been termed X-ray pulsar and was first observed in 1972 by means of special instruments on board an artificial earth satellite.

Even more extraordinary events occur in the binaries sometimes. On August 3, 1975, a hitherto unobserved X source was discovered in the constellation Monoceros. It was hardly noticeable at first but five days later its X radiation was more intensive than that of the "brightest" object in the X-ray sky, Scorpius X-1. In still another five days it became five times more intense. Nothing like that had ever been observed in the X-ray sky.

After a careful study astronomers arrived at the conclusion that this was also a binary-star system one of whose constituents was a neutron star. They supposed that the rate of accretion of matter by a neutron star may increase drastically from time to time. It could be that the first star's companion in the system could be a pulsing star which was alternately contracting and expanding and ejecting large amounts of matter during expansion. It is at such times that X-ray bursts are observed.

There is another incredible phenomenon that may be connected with binaries. Several years ago instruments on board artificial earth satellites registered mysterious short bursts of gamma radiation coming from deep in the universe. They carried staggering amounts of energy; something like a million times more powerful than the energy of the sun's visible radiation. Even more surprisingly, in March 1979 special instruments on board the Soviet *Venera 11* and *Venera 12* stations registered two bursts of gamma radiation coming from one source in the constellation Dorad. One of the bursts was at least 1 000 times more intense than all the gamma bursts ever registered, and several thousand times more intense than the intensity of gamma radiation of the whole celestial sphere. Furthermore, the intensity of the source was increasing at an enormous rate: over a few thousandths of a second it had grown three thousand times.

When the recording of the burst was transmitted to astronomers they were amazed to see the familiar picture of an X-ray pulsar. They had to assume that in this case too they were dealing with the same mechanism of matter in a binary falling to a neutron star. Evidently under certain conditions falling matter may be accelerated to tremendous speeds, as great as one third of the velocity of light. When matter hits the surface of a neutron star at this speed colossal energy is released which induces gamma radiation.

Thus we have been receiving more and more information suggesting that the mechanism of accretion in binary systems is responsible for many events in the observable universe. Further studies along these lines will definitely bring about a deeper understanding of the violent events (i.e. events accompanied by the release of enormous energies) occurring in space.

## A New Surprise

A unique object has been discovered in the constellation Aquarius and designated SS 433. A study of its radiation has lead to the amazing conclusion that it is advancing towards the earth with a speed of about 8 000 kilometres per second and at the same time receding as rapidly. But we know that a material body in real world cannot simultaneously move in two opposite directions. Such a thing can only be observed in a complex system the different parts of which move differently.

Further observations revealed that two gas jets were being expelled from the central region of SS 433, one of which was advancing towards earth and the other receding. The mystery of a "split" object was thus cleared.

As for the central region of this object, it must again be a combination of a black hole and a normal star or a neutron and a giant star. At any rate incredibly powerful physical events are taking place there.

It must be said that gas jets like those in SS 433 are quite common, but usually they are expelled from the cores of galaxies with masses as large as billions of suns, and also from some quasars.

Such ejections may be extremely extended. An ejection in the No. GC 6251 galaxy situated 300 million light-years away from earth is four million light-years long. These gas jets have great mass and carry great energy.

Ejections of matter belong in the category of the most fascinating events observed in space and the study of their physical nature is one of the fundamental problems facing modern astrophysics.

In this light it is especially challenging to find out more about the SS 433 as it is situated in our Galaxy. It can probably be said that we have been lucky because the amount of matter being expelled in the jets is rather large for an object of this kind and it can be expected that this state will not be maintained for a long time. We are therefore direct witnesses of a singular event, the study of which may shed light on many other such events in the universe.

New methods of study have brought about an upsurge in the development of modern astronomy. It is beyond any doubt that already in the foreseeable future scientists will learn about phenomena in space which will enable us to understand and know our own planet much better.

## Some More on the Neutrino

Modern physics and astronomy are intimately related. While space is a laboratory for physics which cannot study many processes in terrestrial conditions, the discoveries it makes in this laboratory facilitate progress in astronomy. So, we are witnessing the interpenetration of two sciences which is a natural stage in the process of cognition.

Neutrino is one of the most incredible particles among the over two hundred elementary particles known to physicists. According to the long prevalent view, the neutrino has no rest-mass and is always in motion exactly at the speed of light. On the other hand, there is no principle whereby theory is prohibited to assume that neutrino has mass which is not zero. This idea was what inspired a group of workers at the Institute of Theoretical and Experimental Physics of the USSR Academy of Sciences to launch a series of experiments to find out what mass, if any, the electron neutrinos had. Although still only preliminary, the results have been sensational: the mass of the neutrino is not zero but between 14 and 16 electronvolts. Not a huge mass true, between one thirty-thousandth and one ten-thousandth of the mass of electron, but the very fact of its existence, if confirmed, is bound to bring about quite a change in our familiar ideas about the universe.

Among the outstanding problems facing astronomy today is the problem of solar and stellar energy. Until recently it was believed that the source of this energy was the thermonuclear conversion of hydrogen into helium. This belief was so firm as to be almost axiomatic. And then a doubt was cast on it.

It will be recalled that if the sun's interior is indeed a seat of thermonuclear reactions, then neutrinos must be born there. Owing to their extraordinary penetrating ability and their very weak interactions with matter these particles must freely escape into solar space and some of them must reach earth. As you know, a special device was mounted to register the neutrinos, but it was found that the number of these particles reaching earth was several times smaller than had been predicted by theory. A number of hypotheses was advanced, some even suggesting that the source of the solar and stellar energy was not thermonuclear reactions but some unknown physical phenomenon. The question still remains open.

If it is proved that the neutrino has mass there will be new possibilities to explain the unsatisfactory results of neutrino observations. Theorists believe that there are three types of neutrinos in nature and they assume that the neutrino with a mass not zero may spontaneously convert to a neutrino of another type. Then it can also be assumed that the solar neutrinos which are to be registered by special detectors may become converted to other neutrinos on their way to earth and that those other neutrinos cannot be registered by detectors.

If it is confirmed that the neutrino has mass many of the cosmological ideas about the universe will have to be revised. We know that the geometry of space is connected with the density of mass. If the density is greater than a certain critical value (about $10^{-29}$ g/cm$^3$) the space of the universe is closed and finite. Until now astrophysicists have thought the real mean density of matter in the universe is lower than the critical limiting value. The neutrino may change this view dramatically. According to available data, to every proton in the universe (estimates are based on the proton since it is the nucleus of hydrogen and hydrogen is the most abundant chemical element in nature) there is about one billion neutrinos. If neutrinos really have mass and even if this mass is several tens of millions of times smaller than the mass of the proton, the total mass of the neutrinos in the universe is 30 times greater than the mass of "standard" matter. *It may turn out that all the stars, planets,* galaxies and nebulas are merely a small contribution to the neutrino background. And this will mean that the mean density of matter is much greater than the critical value. Consequently the universe is closed and finite, and its expansion is to be replaced by contraction some time in the future (after billions of years).

That is not all, however. The universe as we know it today is isotropic only if considered on a sufficiently large scale. If individual fairly small regions of it are considered then the isotropy is upset—cosmic material is concentrated in galaxies and clusters of galaxies. According to the model of a hot expanding universe, all these objects had to be formed at a definite stage of the expansion, as a result of the development of inhomogeneity of the medium. This is how it must have happened: at one of the earlier stages of the expansion homogeneity prevailed although there were insignificant fluctuations caused by gravitational instability and some regions could have become more abundant in matter than others. If the forces of resilience of matter were greater than gravitational forces, the inhomogeneity could have dissolved, but if gravitational forces prevailed over a considerable volume of space then gravitational instability should have developed and large-scale fluctuations should have been set in motion. This model of the universe is being currently elaborated by Academician Yakov Zeldovich and his colleagues.

This hypothesis, however, presents certain difficulties. One of them arises from radioastronomic observations.

Present-day universe is absolutely transparent for the quanta of background (relict) radiation—no detectable absorption takes place. In the past when the universe was only about a thousandth of its present size it was absolutely opaque for electromagnetic radiation and it was wholly dispersed. If space was absolutely homogeneous the background radiation was to be totally isotropic, that is to say, its intensity should have been absolutely similar in all directions.

But the universe is not homogeneous, as it has galaxies and clusters of galaxies, and if they had really originated from material accumulations brought forth by gravitational instabilities, then at a certain stage in its evolution the cosmic medium could not have been absolutely homogeneous. In that case background radiation cannot be absolutely isotropic either and should harbour small-scale fluctuations. Numerous measurements of background radiation were taken to pin-point these fluctuations. Some of the measurements were carried out by means of the Soviet RATAN-600 (Academy of Sciences Radiotelescope). But no fluctuations could be discovered on the basis of the sizes of primordial accumulations of matter which were inferred from the sizes of present-day clusters of galaxies. It must be assumed then that background radiation is not related to those structures. But this is a mystery—galaxies and galactic clusters had to originate from something. If it was not from the instabilities of the medium then what from? No other likely sources are in sight.

This difficulty could be removed provided it were confirmed that neutrinos have mass. It would then be possible to build a neutrino universe model. The line of reasoning would be as follows. At the earliest stage of expansion of the universe small-scale random instabilities could arise from neutrino gas filling the universe. But in that period neutrinos were extremely energetic and the gravitational fields of small clots of matter were inadequate to bind the neutrinos to themselves, and gradually such neutrinos fell away and were dissipated.

As the process of expansion continued the neutrinos began to lose their speed and, as has been calculated, some 300 years after expansion had set in the clots of material which had become larger could begin to capture them. Such clots had to be as massive as $10^{15}$ solar masses. Gradually they became more and more massive, their gravitational fields grew in intensity and more and more neutrinos were captured. About a million years after the beginning of expansion the accumulations of matter could also capture standard matter—neutral gas. This matter accumulated in the central regions of the invisible neutrino instabilities and developed into the clusters of galaxies we observe today. Calculations show that the mass of that matter was only a few tenths of the total mass of the neutrino accumulations.

In this way the most of the mass of the primary instabilities from which clusters of galaxies formed later was opaque for what we know as background radiation and could not upset its isotropy. The mass of standard matter in the neutrino instabilities was plainly not enough to cause such fluctuations in the intensity of background radiation which could be registered by modern instruments. Thus if neutrinos have mass then the contradiction between the modern view of the origin of galaxies and the results of measurements of background radiation can be disregarded.

There is one more question which can be cleared if neutrinos are proved to possess final mass. It is the question of hidden mass which astrophysicists have been trying to settle for a number of years now.

There are two ways of determining the mass of the clusters of galaxies. The first is by the cluster's luminosity: the greater the mass of the cluster the greater its luminosity. The second, on the basis of Newton's law of gravitation and the motions of galaxies in relation to each other within the clusters governed by this law.

Data obtained by these two methods are widely different: the mass worked out on the basis of the law of gravitation is many times greater than the value inferred from the intensity of luminosity. One of the possible explanations is that the clusters harbour nonluminous objects which contribute to the aggregate mass but have no effect on luminosity. It is these hidden masses that accelerate the galaxies within the clusters to high speeds. What is the physical nature of the hidden masses?

A number of theories have been put forward suggesting that they were gas, dust, stars of low luminosity or black holes. But not one of them could explain the state of affairs satisfactorily. So the question is still unanswered. Clarity may be introduced by the neutrinos. If they have mass then their contribution to the total mass of galaxies in the clusters will be considered sufficient to account for the discrepancy arising in the determination of mass by the two methods. The final conclusion is still in the future.

How feasible is the hypothesis that the mass of the neutrino is not zero?

It will be recalled that the possibility of neutrinos being in existence was predicted on the basis of beta-decay, a process whereby the nucleus of a chemical element, gives up an electron and becomes the nucleus of another element. Physicists noticed that the energy of the escaping electron in some cases was smaller than had been predicted by theoretical calculations. The prominent Swiss physicist Wolfgang Pauli suggested that the deficient energy was carried away by a yet unknown neutral particle which did not interact with matter in any appreciable way and therefore remained unnoticed. This particle was called neutrino, and its existence was confirmed experimentally.

In principle beta-decay can also be used as an indirect indicator in establishing whether the neutrino has mass. Soviet physicists staged a series of experiments on the basis of the beta-decay of tritium in which the nuclei of this element release electrons and transform into atomic nuclei of an isotope of helium. If the mass of the neutrino is zero then among the electrons released by tritium nuclei there must be some that possess the maximum energy possible for this reaction. If the neutrinos have mass then the maximum energy of the escaping electrons must be slightly lower and the difference in the energy levels will depend on the mass of the neutrino. It was on the basis of such experiments that the preliminary conclusion was made that neutrinos have mass which is not zero.

American physicists have also been working on the problem of neutrino mass during the last few years. They based their research on the assumption that if the neutrino had mass the neutrinos of one form could transform into another, and if the mass was zero no such transformations could take place. They reported they had really discovered such transformations, but their evaluation of the mass of the neutrino was lower than the value reported by the Soviet physicists. Some time later the American result was called into question.

Thus numerous fresh experiments and observations will have to be carried out before the question of neutrino mass can be settled. But here one analogy suggests itself. You remember that the neutrino was discovered when it was necessary to explain the deficiency of energy in beta-decay, and by the fact of its existence the neutrino cleared the mystery. Could we expect something like that to happen now and proof that the neutrino has mass will clear several astrophysical mysteries? As one well-known scientist has remarked, if it is proved that the mass of the neutrino is zero after all, then it will be necessary to "invent" another particle which hardly interacts with matter but which has mass.

Analogies in physics and astronomy naturally are not proof, but they are bound to stimulate further research into the question of neutrino mass.

This is why careful consideration of possible astrophysical consequences of proof that neutrino has mass is necessary already today.

## In Search of Extraterrestrial Intelligence

The question of whether there is organic life elsewhere in the universe and whether there can be extraterrestrial civilizations has become a major issue both for scientists and the general public. Despite the fact that not a single living organism has been discovered outside our planet, modern natural science has made such great progress that it is now possible to put this question on a firm scientific foundation and research is being conducted by scientists working in many fields.

It may seem at first glance that the available scientific knowledge definitely testifies to the possibility of a wide distribution of intelligent life in the universe. First, if living organisms originated on earth naturally, in the process of the planet's evolution, it is logical to assume that similar evolution can take place on other space objects of the terrestrial type. Second, carbon which is the chemical basis of living matter is one of the most widely distributed elements in the universe. Third, it has been established by the method of molecular astronomy that synthesis of complex organic molecules from which organic life can originate is taking place in the clouds of gas and dust filling interstellar space.

But all this still remains in the realm of theorizing as the actual reality is much more complex. Evidently when planets form from gas and dust the organic molecules contained in this material are destroyed. This means that for living organisms to evolve on a planet it is necessary that "local" prebiological compounds should first come into being. It seems that even the wide distribution of organic molecules in the interstellar medium cannot guarantee the origin of organic life on bodies of the terrestrial type.

It is even hard to predict if life can evolve on other space objects because science cannot yet explain how the amazing process of self-organization of matter takes place. How inorganic matter becomes organic? This is one of the fundamental problems science has to solve, and the deeper it delves into it the more complex it looks. It does not know, in particular, what set of conditions must come about to give rise to organic life. Consequently, it is yet powerless to determine how often such conditions could have developed during the evolution of the universe. From this springs one of the major uncertainties encountered by those who are engaged in the search of extra-terrestrial civilizations.

It must also be remembered that even the most sophisticated methods of contemporary astronomic research cannot spot planet systems even among the closest star configurations with a sufficient degree of certainty. At any rate not a single system like the solar system has been registered. This fact is of special significance, bearing in mind that scientists are confident that among the myriads of space objects only planets can harbour life, and especially rational life.

At present new improved methods of searching for planetary systems are being elaborated but it is not so soon that any practical results can be expected.

Thus science still knows too little to give a theoretically substantiated answer to the question under study. It is natural therefore that the observational aspect of the problem plays an important role at the present stage. We mean the attempts to detect signals from operating radio transmitters or other signs of practical activity of extraterrestrial civilizations. In the recent past such attempts have been made by means of the world's major radiotelescopes, including those in the Soviet Union. Radio observations of individual regions of space have failed to register a single "transmission" which could even remotely be suspected of having an artificial origin. Neither have any other signs of intelligent activity been detected. In other words, scientists still do not have a single fact which could directly or indirectly serve to prove the existence of rational creatures outside our planet.

Several explanations have been proposed. The eminent Soviet astrophysicist Iosif Shklovsky thinks that it may be assumed that the terrestrial civilization is unique in our Galaxy and even in the Metagalaxy. His argument is that if we suppose that there are many civilizations in the universe then, owing to their naturally uneven development, they must have different scientific and technological potentials. In other words, there must exist civilizations that are behind us and those that are ahead. In particular, there have to be at least a few "supercivilizations" that have been able to harness energies comparable to the power output of their galaxies. The scale of practical activity of such civilizations must be such that they could not go unnoticed by earthlings. But since earthlings have failed to discover any signs of such activity then there can be no such civilizations. And if there are no such civilizations there can be no extraterrestrial civilizations in general, for otherwise some of them would be bound to develop into supercivilizations.

Other scientists believe that civilizations on other planets do not disclose themselves not because they do not exist but because there are reasons for it. Corresponding member of the USSR Academy of Sciences Vsevolod Troitsky has proposed the following theory. The model of a hot expanding universe pictures the earliest stage of evolution as having no stars and no planets, nor even molecules or atoms. All of these formed much later and so the conditions essential for the development of living structures matured in the universe at a certain stage of its history. It was then, according to Troitsky, that life originated practically simultaneously on various space objects. This means that there can exist no civilizations more highly developed than our civilization which is why we cannot find any traces of them.

According to other scientists, at any level of development of other civilizations their activities in space must be limited by difficulties with energy supplies. For example, the development of a powerful radio transmitter for establishing contacts with other intelligent beings in the universe by beaming signals in all directions would have required such colossal amounts of energy that it could jeopardize the very existence of this civilization. This is not to mention the great efforts such a project would involve. A civilization could undertake it only if it found it vital.

So, the question remains open. No civilizations have been discovered outside the bounds of our planet and the prospects of discovering one are bleak.

Then what is the sense of this quest? In the words of Academician G.I. Naan of the Estonian Academy of Sciences, studying the question of extraterrestrial civilizations helps us to study ourselves better.

Humanity has achieved a stage in its development when it is more than ever before aware of its oneness with the universe, aware that the physical laws governing their planet are identical with those governing the rest of the universe. To know these laws today means to be able to plan our work more efficiently and to forecast our future on the basis of scientific knowledge. The research into the question of extraterrestrial civilizations at the present level of natural science appears to be one of the most effective ways of achieving our goals. By trying to learn about the possibility of "cosmic existence" of a civilization in general we learn about our own existence in space and study our civilization from what can be described as its reflection in a cosmic mirror.

The question of establishing contacts with extraterrestrial civilizations and exchanging information with them should be examined in the same light. This question too is of enormous importance, regardless of whether we are ever to establish such a contact in reality. When we devise ways of information exchange between reasonable beings in different cosmic worlds, which probably have different scientific ideas about nature, we also find ways of developing "mutual understanding" and interaction between man and machine.

## The Imp (science fiction)

The ship gained a circular orbit and was now cruising around the third planet in the system of the yellow-green star with a surface temperature in the region of 6 000 degrees. The flight commander and other members of the expedition assembled for an urgent conference in the wardroom.

"We have made an outstanding discovery", the Commander began. "It will have far-reaching consequences. We have found another civilization apart from our own, and now we know we are not the only ones in the universe. We have cosmic brothers, our intellectual equals."

"What of it", the Biologist grunted, "if any contact with those 'intellectual equals' of yours is absolutely out of the question?"

"Why do you say absolutely?" the Physicist objected. He was very young, the youngest of them, and very impatient. "I think your view is too abstract and your conclusion hasty. I propose we begin the experiments now."

"Hasty?" the Biologist was frowning, "Not at all. Do you want me to start explaining commonplaces?"

"You can try", the Physicist exclaimed heatedly.

"OK", the Biologist said, still frowning, "First, contact and mutual understanding require certain objective conditions. We do not have them. In the chemical sense, the inhabitants of this planet are mainly composed of nucleons and electrons while we are made of neutrinos. This means that for them we are invisible and immaterial, just as our whole technology is. And you may be sure that any attempt on our part to communicate with them will inevitably cause them the greatest psychological shock. It may even be fatal. So much for the 'experiments' ".

"And yet", the Astronomer remarked, "I would not be so categorical about it. After all we live in one and the same universe subject to similar physical laws. And since the civilization we have discovered has achieved quite a high level and even ventures out on space flights, their knowledge of the external world cannot be very different from ours. And this makes a good enough reason for contact. Yes, the reason is similarity in the scientific pictures of the world."

"And what does the Philosopher say?" the Commander inquired.

"I think the matter is much more complicated. It seems to me our Astronomer is too optimistic. And optimism in this case is totally unjustified. Yes, we do inhabit one and the same universe, the same for us and for them. But this universe is infinitely diverse. Consider the numerous connections, relationships and phenomena. Any scientific picture of the world takes shape within a finite period of time, which is why it can embrace a finite amount of connections and interactions. And this means that the pictures of the world portrayed by different civilizations may not only differ from one another but may even fail to have a single area of agreement. Then where is the basis for communications?"

"But we may also assume that these pictures do have some areas of agreement," the Physicist objected.

"Yes, we may, but only in principle. Do not forget that science is a social phenomenon which not only follows its own logic of development, but above all, meets the practical needs of society. Pardon if I have to remind you of such banalities. In short, the pictures of the world drawn by different cosmic civilizations may coincide only if these civilizations have traversed one and the same path of social development. But in our case this must obviously be ruled out. So, that's how it is ..." The Philosopher spread his hands in a helpless gesture.

Gloomy silence followed.

"Then what do you propose?" the Physicist spoke first. "Should we leave them having made no attempt whatsoever?"

"I'm afraid, yes. It's been pointed out correctly here that to establish a contact we need a foundation, something we could rely on in our attempt to start communications. It may even be quite an unexpected foundation. I fail to see anything like that at the moment... And I can't imagine how we could even attempt to make contact with this civilization without risk of undesirable, probably grim consequences..."

"I'm still waiting for you to come to the point", the Commander remarked dryly.

No one said anything.

"I take it we have consensus finally", the Commander summed up the situation.

"But," the Physicist seemed unable to accept the decision. "Can we be off just like that?"

"That's necessity," the Commander replied in an uncompromising tone. "I give you three more hours to make some additional scouting around this planet. After that we are off."

A duty officer entered the wardroom.

"Commander, something extraordinary's happened! A boat is missing."

"What do you mean 'missing'?" the Commander sounded cold. "A boat can't go missing all by itself."

"Right, it can't that's why I think it's your grandson. I can't find him anywhere."

"Chuck? I've said all along we shouldn't take him on such an expedition," his face darkened.

"Is it long since you last saw him?" the Physicist asked the Commander.

"No, he was here just a while ago. He was pestering me as usual, wanted me to play with him. But I told him today wasn't the time for it."

"He also asked me," said the Physicist.

"Me too," the Biologist echoed.

"And me," said the Philosopher.

"Of course he's flown off to that planet," the Biologist confirmed what they were all thinking. "Listen, Commander, we must do something immediately or he may stir up a whole mess."

"Yes, yes, I'm afraid I'll have to delegate you on this mission", the Commander turned to the duty officer. "Take a second boat and be off. Be very careful and remember: no contacts with the locals!"

"Very good," the officer replied crisply and dashed out of the wardroom...

"No, this will not do," Tim Wood crumpled the sheet of paper he had just been writing on and threw it on the floor with feeling.

"It's no good at all," he repeated several times as he paced the room up and down. "It's pointless, dry, boring. A funeral, not an article."

That day Wood did not go to his apartment after dinner as usual, but drove straight to the little cottage he had in the country. He always went there when he had an urgent assignment: the quiet of the place immediately set him in the right mood for work. With him it was almost a reflex which had developed over the years: the minute the car crossed the city boundary and the motorway taking him to what he called his "summer residence" plunged into the woods, he felt relieved of the burden of everyday cares and concerns, of the tension of work and the hustle and bustle of the big city. His head would clear and ideas he had squeezed out of his brain with such effort back there in the cramped editorial office would begin to pour forth freely, all by themselves. Often the article would be all there in his mind, ready to be typed by the time he pulled to a stop at the gate.

Not today. Nothing worked today, neither the beautiful road through the sun-drenched forest, nor the solitude of his place. Ideas would not come today.

"I knew this was going to happen sooner or later," Wood was grumbling to himself as he continued pacing the room. This was also one of his habits: to talk aloud while working—it helped his thinking process. "The reader wants sensations. And what is there to shake a modern individual out of his composure? But he wants excitement all the same. He is not interested in a straightforward account of a scientific discovery or something, not even an outstanding discovery. No, let's have something extraordinary, he says."

Deep in his heart Wood knew that it was not so much the reader as the Editor. He had long become reconciled to the fact that he wrote for the Editor.

"Damn him, I can't invent sensations all the time. There has to be a ring of truth in them after all. Enough is enough. I'm through."

Wood stopped running around the room and dropped into an arm-chair, staring vacantly at the wall he was facing.

It is hard to say how long he would be sitting there like that if he hadn't noticed something strange happening a few moments later. Right in front of him, on the wall between two windows, three wooden-framed landscapes an artist had given him were hanging on silk cords suspended from a thin metal rod running beneath the ceiling. Suddenly Wood saw the paintings begin moving slowly upwards as if someone was turning the rod and winding the cords on it.

Wood's eyes were opening wider and wider as he watched the paintings crawl to the ceiling.

"What the hell!" he muttered and shook his head to get rid of the vision. "I don't remember drinking anything strong today..."

The paintings began descending slowly and were soon back in their places.

"No, this won't do. One can go off the rocker in no time it seems." Wood jumped from the armchair with determination and grabbing a clean sheet of paper on the way sat to the desk. "Work is what I must do."

He thought for a moment and reached for his ballpoint at the other end of the desk, but jerked his hand back as if he had touched burning hot iron: the pen rolled away from him all by itself. Wood reached out for it again but the pen jumped away once more.

Wood's sense of humour had helped him out many times in the past and this time it did not let him down either.

"This is becoming interesting," he said with a short laugh. "Could it be that my house is haunted? No, it would be just too good. Enough to keep me busy the rest of my life."

He looked around the room but did not notice anything out of the ordinary. All things were in their places and showed no sign of going against laws of nature.

"OK then," he muttered with some disappointment. "I must have imagined it."

That same moment the sheet of paper lying before him on the desk lifted itself off into the air, stopped right in front of his face and brushed his nose several times.

"Marvellous!" Wood cried excitedly. "That's exactly what I wanted!"

He dashed to the typewriter, inserted a sheet nervously and typed the heading of his future article: "The Ghosts are Back!"

He jerked the carriage to the left and sat thinking over the first sentence. The typewriter suddenly came to life and typed out the following, as fast as a computer:

"Aren't you afraid of me?"

Wood was staring wildly at the phrase which had materialized in such a peculiar way. But he was already getting used to the queer happenings.

"Happy to welcome you!" he typed in reply.

The typewriter was "silent" for a while and then went on:

"Play with me!"

"I say!" Wood exclaimed in admiration. "The devil take me if I ever heard about ghosts playing with people!"

"I'm not a ghost," the typewriter hammered, "I'm from another planet."

"That's what I call going from bad to worse," Wood exclaimed. "Where are you?"

"I'm here beside you," the typewriter rattled, "But you can't see or feel me, I'm made that way. But I can hear you. Play with me."

"Play," Wood was thinking fast, "But what game could I play with a creature I can't see or hear? Not hide and seek, for God's sake, it's enough we manage to talk and are even getting to be almost like old friends."

"Where did you learn our language?"

"We've studied it," typed the stranger.

Studied it? Then perhaps...

Wood rolled the platen up a little and typed the first letter that came to his mind—*L*.

"This is a word game," he explained. "We'll add letters on the left and right of the *L* in turn, trying to make the longest possible word. The one who completes the word loses the game."

The letter *U* appeared on the right of the *L*.

"Well," he said reflectively, "not bad at all for a beginner."

He thought for a moment and added the letter *B* on the left.

"This is a bit more difficult."

What he had in mind was the word "blur". His guest was sure to lose if he went along with it—there would be one letter less to write on the right.

"Something to think about, isn't it?"

Instead of "answering" the typewriter added an *N* on the right! Wood stared at the combination in disbelief.

"What the hell?"

He could think of only one word—"blunt" ... That the stranger was turning out to be so clever wasn't as bad as Wood's realization that he was going to lose.

"Well done! You win," Wood sighed. "Your turn to begin."

The sheet in the typewriter moved up and the letter *Z* was typed on it...

Wood lost the second round even faster and very soon all was over. After five rounds the score was 0 : 5.

"Another match?"

"No, it's boring. Think up something else."

"All right", Wood replied and suddenly realized he had missed several opportunities in the first game. He shouldn't have given in so soon. Of course he would have lost anyway, but with a point or two to his credit. It would have been an honourable defeat...

"This is what we'll do," said Wood. "We'll compose words from the letters in some word we'll choose. The time limit will be, say, fifteen minutes. The one who has more words by then, wins."

"I see," the stranger typed, "Let's have the word."

Wood inserted a clean sheet of paper and typed the first word that came to mind, then took another sheet, put it on the coffee table and reached for the ballpoint on the desk. This time it made no attempt to jump away. Wood wrote the same word at the top of the sheet.

"Let's begin, the time is fifteen minutes."

The typewriter burst forth like a machine-gun, rattling without a stop. By the time Wood had managed to write three words, his guest had typed out a whole column and was pounding away at the same mad pace. Exactly fifteen minutes later the pounding stopped. Wood had 63 words. His opponent had 155! Wood skimmed through the enormous list incredulously. Those creatures from an unknown world had really learned a thing or two about the terrestrial civilization. The visitor's collection of words showed a thorough knowledge of the human anatomy, of physics, chemistry, history and much else.

Wood raised his hands.

"I surrender. What will we do next?"

"Play," the typewriter "replied".

"What could we play now?" Wood was thinking. He was all worked up and did not like the idea of losing again. "I must defend the honour of the terrestrial civilization. I must think up a game at which he will not be able to come out on top of me."

Wood was fevereshly considering all the games he knew. Dominoes? Too dull and too long, especially considering the fact that there were only two players. Besides, there were no dominoes in his place. Table tennis? The idea seemed so ridiculous that Wood began to laugh: how do you play tennis with an invisible partner? Billiards perhaps? That was it! Why hadn't he thought about it in the first place? He loved the game and was considered a very good billiardist. Few of the people he knew could outdo him in billiards. He had even seen to it that there should be a billiard-room in his cottage.

"Let's move to the other room," Wood shouted as if afraid his partner would not hear him, and jumped from his seat.

He grabbed the typewriter, threw open the door of the billiard-room and put the typewriter on a chair.

"Do let's start!" The creature was obviously impatient.

Wood took a cue.

"The idea of the game is to drive these balls into the pockets. The balls are numbered—1 to 15. The one who gains 71 points first wins. You may use only one ball, this striped one, with which you strike others. Like this." Wood regarded the green cloth on which the billiard-balls were lying in disorder, bent over them and struck almost without aiming. The ball slid into the pocket neatly, not even touching the edges.

"I got it!" the guest typed. "Now do let's begin!"

"In a hurry, are you? Just you wait!" Wood was thinking as he collected the balls into the wooden triangle. He took careful aim and struck. The striking ball bounced off the back cushion and quietly joined the others without upsetting the triangle.

"Your turn," Wood said and it was only then he began to wonder if the stranger would be able to play at all. How would he hold the cue? Wood had no idea what he looked like. But the word "looked" was obviously out of place under the circumstances...

Wood's doubts were dispelled immediately: the striped ball performed a sharp spin and destroyed the triangle arrangement, sending the balls rolling in all directions.

"Oho! It's going to be quite a game!"

The journalist was watching the invisible creature's actions with growing fascination. The striking ball rolled to a corner and stopped a millimetre away from the jaws of the pocket. It was absolutely impossible to gain anything from that position.

"What a guy!" Wood thought with admiration. "To grasp the point so fast!"

It was his turn now. He sized up the situation and struck, intending to place the striped ball in the most awkward position for his partner. The ball rolled and Wood watched it with a satisfied grin: let him try now.

But his satisfaction was premature. The stranger typed the numbers in the series he was going to play. It was unbelievable to say the least. Wood jumped closer to the table. The stranger's cue made a short and precise lunge. The striking ball jumped from its place, ran into a side cushion, bounced off and kicked the first ball in the announced series. It recoiled, setting in motion all the others exactly in the planned order. There was a soft click as the last ball slid into the net.

Wood was gaping as if unable to utter a word—never had he seen anything like that in all the years of his rich billiard experience. Meanwhile his partner was devising more and more complicated, utterly unfeasible, series. The balls obediently zigzagged now into one pocket now into another. Wood only just managed to fish them out. When the stranger scored over 50 points Wood put down his cue. And he was right: three more kicks and the game was over.

"Shall we play another game?" drummed the typewriter. The visitor from space must have enjoyed the game.

"No, I don't think it's worth it," Wood couldn't conceal his disappointment: he had pinned such great hopes on the billiards. "Let's play something else," he said.

After three crushing defeats Wood realized that to compete with the stranger in games where everything depended on accuracy of calculation was senseless. Evidently this invisible creature's brain was comparable to a high-class computer and Wood's only hope was to offer him a game where everything would depend on unforeseen circumstances. Of course to win in that sort of game would not amount to much in the way of proving his intellectual superiority, but at least they would play it on an equal basis.

"I know what it will be. Dice. We'll play dice," Wood decided and got a box with two ivory cubes, a present from an Indian journalist.

"We'll throw these cubes in turn," he explained. "The winner will be the one who scores, say, 50 points. When the cubes have been thrown they mustn't be stopped or touched in general," he added as an afterthought, remembering about the advantages his partner could gain from his invisibility.

"Let's begin." Wood pushed the billiard-balls out of the way and threw the dice on the green cloth.

The cubes turned in the air a few times and landed, with the upper sides showing three and four incised dots.

"Seven points," Wood summed up. "Your turn."

The cubes instantly jumped into the air, rolled the length of the table and stopped. Wood saw that both cubes showed the sides with the maximum six dots on them—12 points. Was it a coincidence? Now he threw the cubes with less assurance. He had a six and a five.

"Not so bad," Wood thought with some of his confidence restored. "Let's see what happens now."

The dice flew into the air all by themselves, as it were, rolled on the green field and stopped. Twelve points again!

Wood was finishing the round, all his interest in the game gone: his partner produced two sixes every time his turn came. Having scored 48 points after four attempts, he threw the cubes once more to have the two points necessary to make a neat 50.

So this game was no good either. Wood had no reason to suspect his partner of dishonesty. Evidently he knew how to measure his throw so that the cubes made a definite number of revolutions and came to rest with the necessary sides on top."

"Chance is no help either." Wood was reflecting with some disappointment. "But what kind of chance is it when it can be calculated beforehand?

For me it's chance, but for him it isn't. I need something where chance can be ruled out completely."

It was then Wood remembered about the uncertainty principle, a fundamental principle of quantum mechanics. He had interviewed physicists working in that field many times, wrote popular science articles about events occurring in the microworld and had a fairly good understanding of the subject.

The uncertainty principle stated that the behaviour of a microparticle, say an electron, could not be calculated beforehand as it was governed only by the theory of probability applicable only to a substantially large number of events.

Wood went to the TV set and switched on the entertainment unit. He reasoned that since the main component of the unit was a random-number generator in the work of which electronic processes played a major role, the data it generated could not be predicted.

"You must name any six numbers from one to fifty," Wood began yet another explanation. "After that I'll press a button and six numbers picked at random by a special attachment to this set will appear on the screen. The one who guesses more numbers, say, after five attempts, wins. I'm beginning. Let it be 3, 8, 17, 21, 46 and 48. Now we'll see how good my choice was."

Wood pressed a button on the display panel and six numbers flared up on the screen: 2, 17, 29, 35, 36, 41.

"One guess — one point," he said. "Your turn."

The numbers 6, 23, 34, 41, 43 and 49 appeared on the sheet in the typewriter.

Wood pressed the button and glanced at the screen with interest: 5, 23, 34, 42, 43, 50.

"Only three 'hits' this time. Things are looking up," commented Wood to himself.

The stranger guessed two numbers in the second series and four in the third. The fourth attempt was one-hundred-per-cent successful—all six numbers coincided. In the fifth series the result was more modest: only two guesses. In all, the visitor from space guessed correctly 17 times and Wood succeeded only three times. He was the loser again and again the score was quite impressive, even though the stranger's win was not absolute.

"Well, at least my defeat is honourable this time, and his is not a one-hundred-per-cent win. But still it seems he can programme the development of microprocesses much more accurately than our earth-bound physicists can."

That the stranger could compete in things associated with numbers was obvious. Wood even suspected that his partner wouldn't lose even to a most sophisticated computer. But what about competing with human intellect? Up till then all they had dealt with depended on the amount of information remembered, on the speed with which this information could be produced, on accuracy. Speed and accuracy. And intellect?

Wood stepped to the bookshelf resolutely, pulled down a chess-board and placed it on the coffee table beside the type-writer. He was a versatile man and it was probable that he owed some of his versatility to journalism. He had a good mathematical mind besides, and was a fine chess-player although he never took part in competitions.

"We'll see, we'll see," he was muttering as he placed the chessmen on the board.

The explanations took ten minutes. Then Wood asked his guest to solve several problems to see how well he understood the rules. The stranger was through with them in a few moments. Then Wood offered him two rather complicated combinations. They took a few seconds. They could begin.

Wood arranged the chessmen on the board.

"Begin, you play white," he said.

He glanced at the typewriter expectantly but the same moment saw a white pawn make a move.

"Why not?" Wood thought. "If he can use the typewriter and kick the billiard-balls, he can certainly move the chessmen."

A fierce battle developed. First the visitor responded rather fast and even though he hadn't been taught the subtleties of theory his moves were faultless. But as the situation became more and more complicated, Wood had to wait for his partner's moves longer and his decisions became more and more questionable. It seemed he no longer managed to calculate all the possible versions beforehand. It was then Wood made a deliberately reckless move. A dramatic turn in the situation followed. It became so confused it was now practically impossible to calculate even one move ahead. It was one of those situations where only a player's intuition could help.

"Well, well, we'll see," Wood muttered as he sacrificed a knight.

Wood wasnt't sure himself where his last move would get him, but his keen intuition told him that whatever his opponent would do now, his position would be extremely difficult.

The visitor showed no sign of life for a long time.

"So this is where your weak point is," Wood concluded triumphantly, "you also have to lose sometimes".

The white had still made no move. Instead, the typewriter came to life suddenly and pounded out the following:

"I can't finish the game. They've come to fetch me," Wood read.

That was all.

Wood felt he had been cheated out of his victory. It would have been his first victory over the stranger from space, a victory which would have proved that human intellect, even if not superior, was doubtlessly sufficiently developed to establish contact with a new civilization. And this victory had been denied him so cruelly.

But Wood immediately recalled himself. After all, was it so important that he hadn't been able to say the last word? It was much more important that he had managed to overcome the visitor despite the latter's computer-like mind. And was that the only thing that meant?

Wood jumped from his chair. The enormity of what had just happened dawned on him only now and it was like a blow. In the excitement of the game he had completely ignored the extraordinary aspect of the affair, had failed to realize this was the only real sensation he had come up against in life, that it made all the other sensations he had written about pale and insignificant in comparison.

And he also thought that the main thing was not that the existence of extraterrestrial civilizations was now an indisputable fact and not that man had achieved a level which enabled him to communicate with intelligent beings from unknown worlds even if they were totally different from him, but that contact with them was feasible. And Wood now knew how it could be established...

The duty officer entered the wardroom, followed by a smiling Chuck.

"Commander, I've brought him," the officer reported.

The Commander gave Chuck a stern look. The latter continued smiling serenely and it was obvious he did not feel guilty at all.

"Well, I'm listening," the Commander said turning to the officer.

By the end of the officer's report the wrinkles on the Commander's face had smoothed out and his eyes were sparkling.

"It's great! Now we know what to do!" The Physicist and the Astronomer exclaimed together.

"Don't let's hurry", The Commander cut in. "We must think over everything carefully, take stock of every circumstance, outline a plan of action. This will be done by other expeditions. But I believe we've found the key."

Meanwhile journalist Tim Wood, sitting in a small cottage lost among age-old trees on the far planet earth, quickly inserted a blank sheet in the typewriter and typed the title of his new article, the most important one he had ever written. The title consisted of three words: “Contact Through Games!”

“Play is vital. No living being, especially one endowed with intelligence can do without play,” he typed without pausing. “And we can well suppose that this is true not only of the inhabitants of our planet but also of those of any other world, whoever they may be. This is a quality that all rational beings in the universe must be sharing..,’’

The article was ready by the evening. Wood took the last sheet out of the typewriter and went out on the porch. The night sky was shining with the brilliance of starlight. Looking up into the fathomless space above, Wood noticed a blue star flare up momentarily and disappear into darkness. That was probably the space visitor’s ship starting on its way back to its home planet. Or it only seemed so to Wood.

For all its ficticiousness, the story touches on the very real question of whether there is other intelligent life in the universe and whether it is possible to establish contact with it.

If we accept that extraterrestrial civilizations do exist, we must also accept that the chance of coming upon a society of rational beings that look like earthlings, a society which has traversed an analogous path of social development and possesses the same amount of scientific knowledge, is extremely slim. This means that the scientific views of the world developed by earthlings and by some other civilization must be glaringly different from each other, different to the point that they do not have a single area of agreement. For a set of scientific views encompasses only a portion of the infinitely diverse world and depends on the history and evolution of only one particular civilization.

To establish contact with another civilization in the universe is, therefore, an extraordinarily complex task.

## Chapter 4

# What If?

### An Even Stranger World Is Imminent

The popular Soviet author Daniel Danin's book *A Strange World Is Imminent* was published in the early 1960s and immediately aroused the liveliest interest of the reading public. What world was meant and why was it to be strange and imminent? The book dealt with the 20th century revolution in physical conceptions, with modern physical ideas that had completely upset accepted notions, and, by virtue of this fact, were believed by many to be nonsensical or even mad, but have since then been fully confirmed by experience.

Man is ordinarily surrounded by the world of classical physics and small wonder, therefore, that he cannot often reconcile his conceptions to those brought forth by present-day developments in physics and astrophysics. Is it easy to believe that a body's mass depends on its speed, and therefore, that the mass of a proton or neutron may, in principle, turn out greater than the mass of our whole Galaxy? Or to accept the view of some physicists that the collision of only two particles may give birth to hundreds of billions of stars? Or to imagine a microparticle whose speed and position in space can under no circumstances be measured simultaneously and accurately because it is in the shape of a flattened, streaming cloud? Or to visualize the monstrous density of some bodies in space?

These are just a few of the "strange" facts discovered in the world of modern physics and astrophysics. But the "strangest" of them all is that we live with them and among them. They do not exist away from us, say, in a building across the way which we may enter one day or never enter at all. This world is here all along, but it is often too amazing for us to notice it, for the time being, that is.

If a charge of TNT is put into a stove, it may burn quietly and produce heat. But the same charge may explode rending the stove to pieces. This means that the latent properties of TNT will be brought into play by the creation of a set of specific conditions.

As has been mentioned, according to the theory of relativity the mass of a body increases as its speed is increased. Thus, our mass increases if we are in a moving plane or a car. But the increase is so infinitesimal that it not only fails to play a significant role but cannot even be measured by any modern means. Still it does exist and has to be taken into consideration, just as many other facts discovered by the theory of relativity, when designing and constructing atomic and nuclear installations. And since science is never going to stop in its cognition of the external world, it will inevitably discover ever more subtle, extraordinary phenomena.

The beginning of the century saw an explosion of outstanding physical discoveries that have produced an impact on many fundamental concepts of the external world. Since then our knowledge of the structure of matter has grown immeasurably, new phenomena were discovered and new laws and solutions to many problems were found. But all that also gave rise to new questions and new difficulties. It is only to be expected that they may yet lead to a major revision in such notions as those of the particle, the field, space and time, that is, in virtually all the fundamental concepts of modern physics. Our ideas of the balance of the macroscopic and microscopic forms of the existence of matter may also undergo a change. Is the gap between the macro and microworlds really so great?

Experimenters have been discovering more and more new and heavier particles, the so-called resonance particles, with masses far exceeding the mass of the nucleon. Is there a limit to such masses? Can macroscopic objects come into being in ultra-small areas of time-space? Naturally, such a thing may happen only if interaction energies are exceedingly high. So far even modern accelerators have not been able to produce such energies, neither can we discover them during observations of the cosmic rays, our traditional physical laboratory. The point is that the cosmic particles travelling in our region of the universe inevitably lose some of their energy as a result of their contact with the photons of the residual background radiation. Therefore the energy of these particles is automatically "checked" at a definite level and never exceeds it.

Even now the study of the microworld gives rise to problems of a cosmic order, the solution of which more and more often depends on the solution of the major problems of elementary particles physics.

Generally speaking, astronomy today is even more the province of the most staggering discoveries which are requiring or may yet require a basic revision of our concepts of nature, than the elementary particles physics.

Modern astronomy and physics are likely to face us with new surprises, new amazing discoveries, that will lead us to the depths of a truly strange world. This is why it is sometimes worthwhile to view "ordinary" phenomena from an unusual, paradoxical standpoint. In some cases such an approach may help us to clarify a problem and improve our understanding of the meaning of events. We can create paradoxes by simply asking ourselves: "What if...?" Here follows a series of mental experiments that we have entitled "What if...?"

## Overloads and Weightlessness

Any major scientific breakthrough is wont to change the life of every one of us in one way or another. Take the discovery of electricity and electromagnetic waves, the invention of flying machines and the development of transistors; take the missiles and spacecraft of our day.

It can be asserted that several decades from now people will be using missiles for intercontinental communications with as much ease and confidence as they are boarding a jet liner today. Earth-moon communications will become regular and ordinary; people will live and work on space stations and specialists in the new trades of space welding, space assembly work, etc., will be in demand.

But it will be for the first time in history that scientific and technological progress will take man into the fundamentally new medium of outer space, a medium where the standard laws of physics work differently. That development will only be comparable to what will happen if man learns to live on the ocean floor.

It goes without saying that the fundamental laws of physics, and particularly mechanics, are the same for conditions on the surface of the earth, for those on the ocean floor and for outer space. Only they work differently in each of these environments. In the terrestrial conditions these laws are characterized by two main features: absence of visible changes in the speed of motion, that is, in acceleration of the points making up the planet's surface and by the fact that our planet attracts all bodies and causes them to exert pressure on its surface.

The absence of appreciable accelerations is explained by the specifics of the earth's motion in space. Together with our planet we are involved in the two of its basic motions—the diurnal rotation on its own axis and the yearly revolution around the sun. And so, although we are moving together with the earth at a speed of 30 kilometres per second, and together with the solar system, revolve around the centre of our Galaxy at the incredible speed of 230 kilometres per second, we do not feel it since our organism is insensitive to the speed of motion in a straight line.

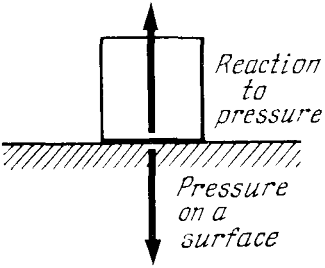
But as a matter of fact, according to one of the basic laws of mechanics, uniform motion in a straight line cannot be detected or measured by any physical means.

And what if it is a case of a system, say a space vehicle, moving with acceleration imparted by its engines or owing to the resistance of the medium? In this case an overload, that is an increase in pressure on the support, occurs. On the other hand, if the vehicle is moving with its engines idling, pressure on the support disappears and weightlessness sets in.

In terrestrial conditions pressure on a surface results from the action of the force of attraction or gravitation. But often people believe that this pressure is precisely the force with which a body is attracted to earth. Were this really the case, we would not observe weightlessness in a spaceship flying to the moon, since in any point on the orbit the ship would be subject to the earth's gravitation. And in general, it is hardly possible to find a spot in outer space where the resultant of the forces of gravitation would be zero.

It should be noted that pressure may be caused by forces other than the force of gravitation, by acceleration, for one. For a body in a state of rest on the surface of the earth gravitation is indeed equal to its weight, but it is only a special case.

Man exerts a certain pressure on the earth's surface, but according to the third law of mechanics, the surface itself exerts absolutely the same amount of counterpressure on man from below. This force of resistance is referred to as reaction. The forces of action and reaction are always impressed on different bodies. In the given case the force of gravity acts on the surface and of the reaction, on the body itself. Thus gravity acts on the body and not on the surface, which means that this force is totally different from pressure on a surface.

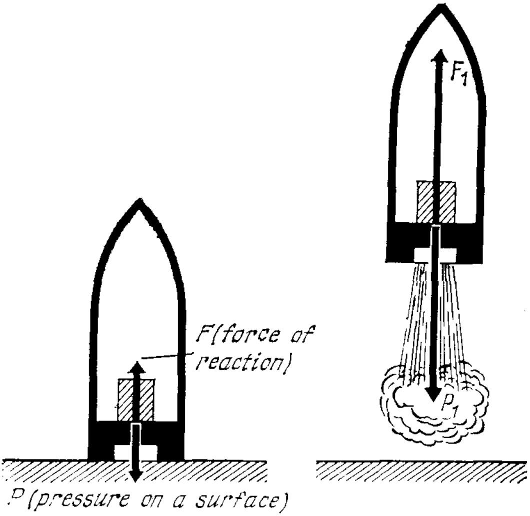


Pressure on a surface and reaction to pressure

If a space rocket is moving with acceleration, the pressure of the surface (outer space in this case) on the rocket increases as much as the actual acceleration of the rocket exceeds the acceleration of a body in a free fall, which is 9.81 square metres per second. In other words, reaction of the surface increases at the stretch of the rocket's motion with acceleration, and, as established by the third law of mechanics, pressure on the surface increases as much.

The ratio of pressure on the surface during a space flight to such 'pressure in terrestrial conditions has been termed overload. For us on the earth's surface the overload is 1. The human organism has adapted itself to this constant overload and we simply do not notice it.

To put it in physical terms, overload means that not all the points of a body are accelerated simultaneously. The force acting on a body, for example, the thrust of the rocket engine, is impressed on a comparatively small portion of its surface. All the other material points of the body



Physical meaning of overload

receive acceleration with a delay, through deformation. It is as though the body is flattened while being pressed to its support.

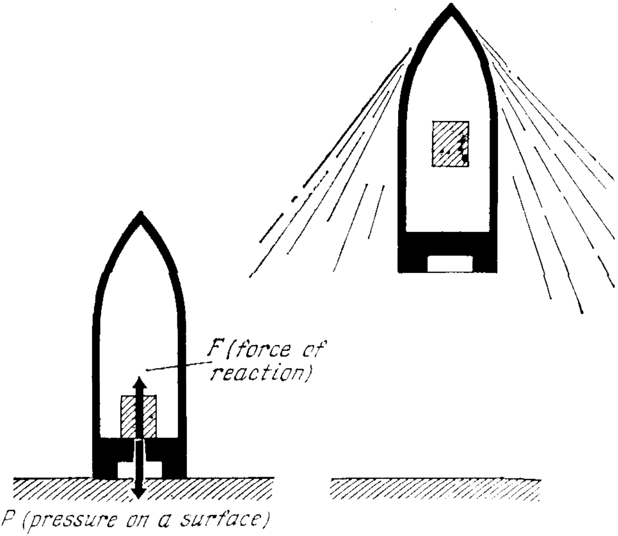
The extensive experimental research, begun by Konstantin Tsiolkovsky at the break of the century and continued in our day, has demonstrated that the physiological effect of overload not only depends on its duration but also on the position of a given body. In the case of overload on the human body, when it is in an upright position much of the blood is displaced to its lower portion and the blood supply to the brain is upset. The internal organs are also displaced lower because of the increase in their weight, causing tension of the sinews. In order to alleviate the dangerous effects of overload the position of the body should guarantee that overload is directed from the back to the chest. This enables the organism to endure a triple overload. As a matter of fact, this is why it is better to rest lying down than standing up.

While those living on earth do experience the action of overload, even though seldom, they know practically nothing of weightlessness. This amazing state sets in when the rocket engines are extinguished and both pressure on the surface and reaction disappear. The familiar perception of top and bottom becomes meaningless and unsecured articles begin to float freely in the air.

There is quite a number of misconceptions associated with weightlessness. Some believe that this state is created when the spaceship escapes "the sphere of the earth's attraction", beyond which there is no air. Others suppose that weightlessness is caused by the action of "centrifugal forces".

But neither view is correct. What conditions cause weightlessness then? The point is that while the rocket is in a free motion in space, it itself and all the things it carries move with a similar acceleration owing to the forces of gravitation. It is as though the surface is moving ahead of the body and the body does not have enough time to exert pressure on it.

But both the motion on the active stretch of the orbit with the engines working and that under the action of gravitation are accelerated motions, influenced by the forces impressed on them.



Physical meaning of weightlessness

Then why is overload created in the first case, and in the second, weightlessness?

This only seems to be a paradox. As has been mentioned, in case of overload acceleration is transmitted to the different points of a body through deformation. If the rocket is moving in a gravitational field, that is without its engines running, this field is practically uniform within the confines of the rocket, which means that equal forces are acting on all its points simultaneously. This is so because gravitational forces belong to the so-called mass forces, i.e., forces acting simultaneously on all the points of the given body or system. Owing to this fact all the points of the rocket receive equal accelerations simultaneously and all interaction between them ceases; pressure on the surface stops along with the reaction and a state of complete weightlessness is observed.

Some physical processes must be expected to occur differently in weightlessness. It was Albert Einstein who posed this interesting question even before the space era commenced: Will a candle burn in a spaceship? He himself answered his question in the negative, believing that weightlessness would not let the hot gases escape beyond the area of the flame, hence oxygen would not reach the flame either and it would go out.

Modern experimenters have attempted to verify Einstein's conclusion by conducting the following experiment. A burning candle was placed in a closed glass jar and dropped from an altitude of about 70 metres. Discounting the resistance of the air, we can say that the candle was under the conditions of weightlessness during its fall. However, it did not go out, only the outline of its flame changed, becoming rounder, and its light dimmed.

It seems that the explanation must be sought in diffusion, owing to which oxygen must reach the area of the flame from the external medium, for diffusion is not affected by gravitation.

And yet burning in weightlessness is different from what it is here on earth. That was one of the facts that Soviet designers had to consider when constructing a unique installation for space welding that was successfully tested on *Soyuz 8* in 1969.

## Can Night be Eliminated?

We know that the coming of night is the direct consequence of the earth's daily rotation on its axis, owing to which the sun lights up only one half of its sphere. Thus, much of their time people live in the darkness and are obliged to use vast amounts of energy for the lighting of buildings and streets at night.

Could we eliminate night for good?

A number of interesting ideas have been expressed on this subject. We have to admit that most of them still border on the fantastic but, in principle, they could be realized in time.

One idea is to have a "hydrogen sun"— a remote-controlled thermonuclear reactor—mounted on an artificial earth satellite in which a regulated synthesis of hydrogen nuclei would be taking place just as it does in the sun. Since this reaction gives rise to temperatures running into millions of degrees, it could indeed serve as a source of light and heat. The satellite's orbit could be calculated in a way that the artificial sun would make its appearance mainly over the unlighted parts of the earth's surface or would most of the time slowly move over the polar regions. Then it would be possible to put an end to the tedious polar night and at the same time to warm up the Arctic and the Antarctic.

Technically this project is unfeasible because no way has been devised to control thermonuclear reactions. But even if such a way is found, it will probably take engineers a very long time to be able to construct a "hydrogen sun" and install it on an artificial earth satellite.

Another clever project also involves the use of satellites. These satellites will not be some sort of space apparatus filled with sophisticated instrumentation, but will be in the form of countless dust particles injected into the lower atmosphere by special spacecraft. The idea is that these particles will form a great dust ring around our planet, not unlike one of the rings of Saturn. By intercepting solar rays passing by the earth to be lost to space and scattering them in all directions the dust particles will send some of the solar light and heat to earth. There will be no more night and the planet's climate will become much milder.

Even now it could be estimated how many dust particles would be required to create the desired effect and what should be the dimensions, position and density of the dust ring. But those are technical details, so to say.

There must be other ways of eliminating night completely or partially. In future it is to be expected that other, technically more feasible projects may be developed.

But can such projects be realized in principle? Apart from the technical difficulties involved, there is nature itself to be considered.

To eliminate night will mean to drastically increase the amount of solar energy coming to earth, hence to upset the regular heat and light exchange leading to a change in climate.

But in nature steady systems, including our planet, are exceedingly complex and self-regulating, and in them a dynamic equilibrium is maintained naturally. An intervention into it may lead to catastrophic consequences: the raising of the sea level, violation of water and atmospheric circulation and disastrous climatic changes.

It must not be ignored, besides, that the living organisms on our planet have adapted themselves to the existing day and night cycle over many millions of years, hence the elimination of night may also produce harmful effects on plant and animal life.

But this does not mean that people will always accept night and winter colds and will not attempt to do anything about it. They will. But it will take time and a most careful scientific preparation.

## People Without Stars

The Roman philosopher Seneca once said that had there been only one place on earth from which stars could be watched, people would be swarming there from all over the world in an endless stream.

Indeed, the sight of the star-studded sky is superb. But is it just the inimitable beauty that is so attractive? What is the practical significance of these observations? Perhaps humanity would be as content without the stars?

Let us imagine that our sky is always clouded, an opaque canopy hovering above our heads, depriving us of absolutely any possibility of watching the stars. Perhaps such a picture is hard to imagine, but it is necessary in order to appreciate the significance of astronomy in mankind's evolution. And then the picture will not be entirely fantastic: we know some celestial bodies, whose sky is eternally obscured by thick clouds, and one of them is Venus, our planetary neighbour. It is likely that in time people will have to live on cloudy planets, or that they will discover civilizations living there now.

But it is hard to picture earth without the stars and the sun. We want to see the sun and the blue sky, the patches of light on water and on green foliage.

Now imagine that all this is gone. There is no blue sky, no patches of sunlight, no stars and no moon. Our sky is always dark. Dusk is eternal and the grey days stretch out for a whole life of endless and hopeless rain....

There are few sunny days in some regions of earth, and they say that people who live there seldom smile. What would people have been like had they never known the sun?

Man is what thousands of millennia and the environment have made him. The physical conditions obtaining on earth explain the peculiarities of his stature, the sensitivity of his sight to certain lighting, the structure of his ear, etc. Definitely the same can also be said of human psychology.

Naturally this reasoning is purely conjectural and may be disputed. But for us it seems logical to think that had people lived under the same grey sky from generation to generation, with one dull day exactly like all the others, then the moral potential of mankind, if I am permitted this expression, would probably have registered a lower point, people would have been less vigorous and less optimistic. Of course this is only a theory. One thing is definite though: had it been so, the earlier stages in human history would have been even grimmer.

Let us recall how people discovered they lived on a sphere. The most convincing proof came from observations of lunar eclipses, when the earth cast its spheric shadow on the moon. They noticed that the earth's contour was a circle during every eclipse. And it is only a sphere that casts a "round" shadow, whatever its position.

Another proof was that receding objects gradually disappeared beyond the bulging surface of the earth. Actually such observations could not be very convincing on the continent because then they could be explained by the undulating relief. Observations on the sea were, obviously necessary. The ever overcast sky would not conceal the fact that ships gradually disappeared beyond the horizon. But from that fact to draw the definite conclusion that the earth was a sphere, it was necessary to compare the results of similar observations made in different parts of the world—it was necessary to see that the earth was "bulging" everywhere. And that required communications between the different parts of the world—sea voyages had to be started. But it would be exceedingly difficult without the stars. It would be dangerous to venture into the open sea before determining the exact location and course of the ship. This is where voyagers had always been assisted by stars. True they could make some use of sunsets and sunrises because, even when overcast, the eastern sector of the sky lights up sooner and in the evening the western sector darkens later than the rest of the sky. Observations could help people see that.

If the earth had always been enveloped in clouds, people would not have learned that certain events were taking place at sunrise and sunset, but by watching the sky generation after generation they would have finally noticed a recurrence of similar phenomena. We can suppose that sooner or later they would have compiled special tables indicating the displacements of the lighted sectors of the sky with the coming of the different seasons and even with the observer changing his station on the surface of the earth. But orientation by the lighted sectors of the sky when it is overcast is very unreliable, because the scattering of sunlight by the clouds makes it difficult to determine the point of sunrise or sunset with the naked eye especially if the mass of cloud is thick and stratified. But we may suppose that since it was important to be able to orientate, people would eventually design special instruments to measure the luminosity of the sky and find the best lighted spot. Their ability to orientate would have greatly increased. Probably the magnetic compass would have been invented much sooner then.

The inhabitants of the cloudy planet would also be faced with considerable difficulties with telling the time. For at the dawn of civilization time was established by the position of the sun and at night, by the stars. The calendars were made on the basis of astronomic observations as well.

That would not have been possible on a cloudy earth. But still it would be much easier to determine the time in such a situation than to learn to orientate. If they had instruments to determine the greatest luminosity, they would also be able to determine the time of day from observations of the movement of the bright area over the sky. They could create a calendar on the same basis, which would most likely state the shortest day as the beginning of winter and the longest, as the beginning of summer. We can also suppose that the difficulties with determining the time would probably have prompted the invention of clock-like instruments much earlier than it had actually been the case.

The history of natural sciences points out the fact, however, that observations of the starry sky, and of the motions of the sun, the moon and the planets are not enough to form a true picture of the universe. At the initial stages the visible motions of celestial bodies were taken for the actual reality, illusions, for truth. Thus the idea of geocentricity, the system of Aristotle-Ptolemy, was born: the earth is the centre of the universe, it dominates the universe, while the celestial bodies are revolving around it.

On reaching a definite stage in its evolution, the civilization inhabiting a cloudy earth would attempt to form a picture of the universe. It would need more than random information on the external world—a system of knowledge which could not be complete unless it included ideas concerning the constitution of the universe and the earth's place in it.

Naturally the veil of cloud would not have concealed certain events occurring beyond it, for it would be from there that light and warmth would be coming to them. Probably they would worship light the same way as our forebears had once worshipped the sun. But it would be extremely difficult for them to devise a picture of the universe that would be in any way scientific. For even when elaborating a most abstract hypothesis, the human brain draws on knowledge, on reality. And a cloudy sky would offer far less to inspire thought than the sight of the stars at night.

Copernicus arrived at his conclusion that the earth was revolving around the sun by observing the looplike motions of the planets against the background of the stars. Giordano Bruno and Mikhail Lomonosov formed their conceptions of many inhabited worlds by comparing the far luminaries, the stars, with our luminary, the sun.

Scientists on an overcast earth would not be able to form any such ideas. They would probably also make attempts, but their picture of the universe would be much further removed from the truth than even the vague guesses of our ancestors.

The lack of any possibility of astronomic observations would doubtlessly hinder the establishment of the fundamental laws of nature and scientific advance in general.

For example, Galileo discovered his famous "principle of inertia" largely as a result of astronomic observations: our earthly experience has nothing to show that a body on which no forces are impressed is in uniform motion in a straight line. Moreover, this idea contradicts "common sense", and it is for good reason that it was so vehemently rejected by Galileo's contemporaries. Meanwhile the principle of inertia is the foundation of mechanics as a whole.

It was also from astronomic observations that another fundamental law of nature, the law of universal gravitation, was evolved. Of course "apples" would fall on the surface of a cloud-bound earth just as they always do, but we must remember that before he arrived at his brilliant conclusion Newton had made a careful study of the moon's revolution around the earth.

It would be almost impossible to discover universal gravitation with a grey sky always obscuring vision. For the force of mutual attraction between objects on the surface of the earth is so small that it can be detected only by very sophisticated experiments.

The theory of relativity, the cause of a veritable revolution in science, is also based on astronomical data. One of the fundamentals of this theory is the assumption of the absolute constancy of the speed of light, i.e. the assumption that light travels with the same speed in all directions. This means that it takes light a definite period of time to cover the distance from its source to the observer. Thus the starlight we observe must have left its sources some considerable time before and we are actually looking backward into the past. But our experience tells us something entirely different: an event is taking place exactly the minute we see it. And it is easy to understand why we think so: terrestrial distances are infinitesimal compared to the distances light travels in one second. It is only observations on a cosmic scale that have been able to destroy our illusion.

It is difficult even to list the remarkable achievements that have been made possible by space studies. Suffice it to recall that it was in outer space that hitherto unknown states of matter were discovered along with new sources of energy.

If we trace the history of many sciences, not only physics, but also chemistry, mathematics and even biology, we'll see that in many cases their achievements were associated with the study of the universe, though probably not always directly. Einstein had every reason to say that the intellectual potential without which modern technology would have been inconceivable, has mainly drawn on observations of the stars.

Scientists beneath an eternally overcast sky would have found themselves in a deplorable situation in this respect. And not only because the invisible universe would not be nourishing them with a wealth of stimulating ideas. In their attempts to understand events occurring beyond the blanket of cloud they would be forced daily and hourly to wage an even more fierce struggle against "common sense" than our ancestors had to.

The civilization on an overcast planet would resemble a person born blind. The study of the universe in the real history of mankind had long been concentrated on the study of visible radiation coming from celestial bodies. Light was called a "messenger of distant worlds". But no such messenger would come to a civilization living in the dark.

It will be noted in passing that people born not only blind but also deaf do have an ability to perceive the external world and even engage in creative work. They receive information transmitted by other than the sight and sound channels.

The inhabitants of a cloudy earth would experience something of the same nature. Deprived of the possibility to obtain information from light, they would learn to study other messengers from the universe, above all, radio emission of other space objects. It goes without saying that they would have managed to make use of the radio emission only on reaching a definite level of scientific and technological advancement. They would not only have to discover radio waves but also to construct exceedingly sensitive radio sets.

Breaking through the cloud canopy would mark a crucial era in the development of our hypothetical civilization. This event would definitely take great effort. But from then on its history would be little different from the development of our civilization during the epoch of aviation and space travel.

To sum up. Even if people had really been deprived of the possibility to observe the stars, they would have, sooner or later, overcome the barriers separating the rest of the universe from them. Thus we can expect that our contemporaries will be able to cope with the astronomic difficulties that will inevitably be involved in the future exploration of cloudy planets.

## If There Were No Moon

Let us now imagine what would happen if the earth lost its natural satellite, the moon. First of all, it would affect the beauty of night: there would be no cool and transparent moonlight, no silver paths on water. But that would only be the visible side of it. There would be no more moon tides, hence sea navigation would have to change. We would be left with only the solar tides, but the sun being such a great distance away, its tides would be far weaker than moon tides.

On the other hand, the absence of moon nights would make astronomic observations easier; scientists would be able to discover more comets, see the smaller planets of the solar system, and so on.

It is also probable that the disappearance of the moon would affect geophysical processes.

But that is not all. Let us recall a few facts associated with the observations of the moon.

The earth sphericity was proved on the basis of the spheric shadow that it cast on the moon during the latter's eclipses.

It was during his telescopic observations of the moon that Galileo discovered mountains on its surface and made the first real breach in the age-old conception of the fathomless void between the earthly and the celestial.

It was from his studies of the moon's revolution around the earth that Newton obtained the final confirmation for his law of universal gravitation.

It was again the observations of the moon's revolution around the earth that first prompted the idea of creating an artificial earth satellite.

The absence of the moon would put an end to solar eclipses.

The role of the moon, however, is not limited to its influence on the development of science. Being our closest celestial neighbour, it is more and more often used as a kind of a testing ground by means of which many operations involved in space exploration are tried out and improved.

The moon was the first radio "mirror" in space which helped to develop methods of astronomic radiolocation. The experiments with radio waves reflected from the lunar surface were the basis for designing special instruments to locate the sun and many planets of the solar system.

The moon is indispensable in the development of space travel and not only because a station is likely to be installed on it, but also because many essential operations involved in space navigation are tried out in the vicinity of the moon.

The moon, therefore, is not a piece of ornamentation in the sky, but an important factor without which scientific progress and space exploration would have probably been much slower.

The absence of the moon would greatly reduce the effect of the phenomenon termed precession. As we know, the earth is slightly flattened at the poles—its polar radius is something like 21 kilometres shorter than the equatorial. Such is the result of redistribution of the earth's matter, caused by its daily rotation. Some of the matter has been displaced from the poles to the equator, forming the equatorial bulge. The moon's gravitation as well as that of the sun and planets, causes the axis of the earth's rotation to describe a cone within about 26 thousand years, with an angle of about 47 degrees at the vertex. This is called precessional effect. It was not always that Polaris was at the North pole and it will not always stay there. In some 13 thousand years the role of Polaris will be played by Vega in the constellation of Lyra.

Although the mass of the moon is not large, compared to the mass of the sun and planets, we must not forget that it is the closest to us. And the force of gravitation is proportional to the square of distance, in other words, it grows weaker with distance. If there were no moon, we would still have precession, only the angle at the vertex of the cone would be considerably smaller.

While causing the precessional effect the moon is also responsible for the nutation, i.e., deviation in precession within a period of 19 years, which is due to certain peculiarities in the moon's motion. Nutation, too, would disappear with the disappearance of the moon.

## If That Were Possible

Here we come to the question of whether it is possible to make a journey into the past, reversing the normal course of time, and return to the present. We will not discuss the purely physical aspects of such a journey, but simply try to imagine its consequences.

Ray Bradbury, a leading American science fiction writer, tells a fascinating and instructive story. The "Time Safari" travel agency arranges an exciting safari for its clients, on a time machine into a distant past, giving them a unique opportunity to kill a dinosaur. But they must judiciously fulfil one condition: they may kill only one beast which will be pointed out by the agency. They are forbidden to touch anything in the old world so as not to find their own world changed in some unpredictable way. And they must stay on the special path laid by the "Time Safari" agency. But one of them violates the rule and steps off the path, crushing a butterfly underfoot. He pays no attention to the accident, naturally, but when the time machine brings him back to our day, he is horrified at the change which had taken place within the few hours of his absence.

Everything occurring in nature is a chain of cause and effect. When going back into the past and interfering in the course of events we would inevitably change the subsequent causation chain. That was why the "Time Safari" people in this story were so precise in pointing out the dinosaur to be killed and laying the special path. They picked a dinosaur they knew would be dead within the next few minutes. Thus they would preserve the chain undisturbed.

Just how a crushed butterfly would change the course of subsequent events and the future of mankind is, of course, a debatable point, but were time machines and travels into the past possible, any arbitrary action on the part of the travellers could indeed seriously violate the chain of cause and effect.

If a traveller, say, into the 11th century should become involved in a fight with people of that time and kill a man, who actually had children in the "normal" course of events, then those children would have to remain unborn, as would have all his descendents. That would mean that dozens or even hundreds of people would have to disappear from today. They would disappear and be dissolved in time, since one link would have been removed from the causation chain which had produced them. Works of art could disappear in the same way, buildings or whole cities, for that matter.

Not a very optimistic future would await mankind if time machines were invented, letting loose adventurers into various epochs. We would always be weighed down by fear of losing someone or something. On the other hand, we could also expect that travellers in time would not only destroy a chain but also create another, bringing something absolutely unforeseen into our reality.

One of the novels by Isaac Asimov, the American scientist and SF writer, deals with possible consequences of travelling in time. It describes an organization that knows time-travel techniques and engages in rectifying and improving the actual reality. Upon discovering a bad period in history the specialists study it carefully, establish its causes and change them in such a way that the harmful consequences' never come. The memory of mankind changes accordingly, erasing all recollection of past events.

Although this work is wholly motivated by good intentions, it ends in complete failure. This is only natural, since society does not live by a written script, especially if this script is based on arbitrary interference into the causation chain. History is history and though chance circumstances do play a significant role in it, its general course is mainly determined by objective laws that inevitably prevail over chance. In order to influence the course of events on a global scale it would be necessary to relive history and change the laws of social development.

Such is the philosophical aspect of this question. Now to the physical aspect. What does physics have to say on the possibility of a journey into the past? It forbids it as a matter of principle, just as it forbids the construction of a perpetual motion machine. Theoretical physics states that no event taking place in a physical system can influence the behaviour of this system in the past; it can only influence its future evolution.

Thus, the physical version of the universal principle of causation states that any effect should have a natural cause.

At the same time we can imagine, although *with difficulty perhaps, that in some regions* of the universe time flows in a retrograde direction as compared to the course of our time. This circumstance could be made use of on a journey into the past, *if only into a recent past (and if* the time flow there is faster, then also, into a distant past). But that would entail crossing from our region into "that" one and back.

Though this possibility has not been studied at all, we can assert that most likely science forbids such transitions as strictly as journeying into the past.

## Faster Than Light?

The theory of relativity states that the velocity of light is the top limiting velocity in the universe. Can speeds exceeding the speed of light exist in nature from the standpoint of modern theory? This is how this intriguing question is discussed by A. L. Zelmanov.

Indeed, according to the theory of relativity, there is a fundamental speed $c$ which is the highest possible speed and which cannot be exceeded by the speed of any body. What is the physical meaning of this postulate?

The speed of one and the same object within different frames of reference is not the same. One and the same object may be in a state of rest in one frame of reference, or it can be moving slowly in another or moving fast in a third. In Newtonian mechanics there is a speed which is the same in all frames of reference, but it is an infinitely high speed. It is a limit speed. The speed of any real body must be finite. In Newtonian mechanics the speed of moving bodies can be limitlessly high.

The theory of relativity also treats of a case where speed does not depend on the frame of reference. It is the case of a body moving at a speed equal to the fundamental speed $c$ which is the speed of light. Thus, the latter is analogous to the infinitely high speed of Newtonian mechanics.

According to the theory of relativity, any displacement of mass and energy and any transmission of interaction of forces can occur only at speeds not exceeding the speed of light.

Bodies whose mass at rest is not zero can move only at speeds lower than the speed of light, and bodies whose mass at rest is zero (photons and probably neutrinos) can only move at the speed of light.

Nevertheless, speeds higher than the speed of light can be observed, however paradoxical it may seem. A case in point is the speed at which a reflected beam moves on the wall. Theoretically it can be made to move at any speed, no matter how great. But it will only be the speed of motion of a lighted spot and not of a material body over the surface of the wall, constituting no displacement of matter or transmission of interaction of forces.

But let us agree on what we mean when we speak of a body's speed. It is always the speed of a body moving in a definite frame of reference, or, to be more exact, moving in relation to a point in that frame which the given body passes at the given moment. Strictly speaking, there is no sense in discussing the speed of a body moving in relation to some other point situated at a distance or in relation to another body that existed in another epoch.

What is the speed of a galaxy moving in relation to the observer on earth? Obviously, it is senseless to consider it, since we are separated both in space and in time.

Then what speed is worth considering? Only the speed of a galaxy moving in a definite frame of reference, embracing the region and the epoch in which we live and also the region and the epoch in which the galaxy was at the moment the light beam received by the observer was emitted.

There are different ways of devising a frame of reference. Let us choose a frame in relation to which our own speed is zero. Then the speed of the rest of the galaxies will evidently depend on whether our frame of reference is deformed with time and if so, how exactly. It would be logical to choose a "rigid", undeforming frame of reference. But that would be impossible, since the mutual recession of galaxies causes the distribution of mass, hence, the geometry of space to change.

Let us try to choose a frame of reference that would at least not deform in the radial directions from the point in which we are ourselves stationed. It would be feasible in an isotropic homogeneous universe, in which the speeds of motion of the galaxies would be other than zero, but always smaller than the speed light. Those speeds, evidently, would at the same time indicate the speeds at which the distances between the receding galaxies and our station on the earth's surface increase.

But as far as theory is concerned, it is more convenient to use a deforming frame of reference to accompany the expanding system of galaxies, that is, a frame of reference in which the speeds of all the galaxies equal zero (if we are to ignore the comparatively low speeds of chaotic motions). In the accompanying frame of reference the distances between the galaxies would not change as a result of their displacement relative to this frame but owing to a deformation (expansion) of the frame itself.

The speeds at which distances between the galaxies change may appear even higher than the speed of light, but they cannot be considered to be the speeds of motion of material bodies.

This situation looks like another paradox. It appears that with the first frame of reference the speed of change in the distances between the galaxies is always smaller than the speed of light and in the second case, the same speed may be greater than the speed of light. But it is only a seeming contradiction for both the distance between any two bodies and the speed at which this distance changes are values dependent on the frame of reference.

## In a World of Faster-Than-Light Velocities

Can faster-than-light velocities exist in reality? As stated above, according to the theory of relativity, no physical process can take place at velocities exceeding the speed of light in a vacuum. The exclusion of such speeds is doubtlessly one of the most fascinating postulates of modern physics.

Nevertheless it can be suggested in principle that along with the world of velocities that are lower than the velocity of light (tardyon-universe, from the Latin *tardus*, slow) there exists another world in which the velocity of light is not the upper but the lower limit of possible speeds (tachyon-universe, from the Greek *takhys*, fast), that this latter world exists undetected as it has no points of intersection with the former one. Of late years a number of works have been published whose authors consider the probability of "supralight" particles which they have called *tachyons*.

The curious fact about this hypothesis is that it does not contradict the special theory of relativity, but on the contrary makes it more harmonious and consistent with a world lying beyond the barrier of the speed of light. As V. S. Barashenkov, Doctor of Physics and Mathematics, has noted, the tachyon hypothesis may be right or wrong, but it blends with the special theory of relativity very naturally and succeeds in creating a totally wholesome picture. He added that although the truth of this theory could only be proved by experiment, the very ease with which it is generalized to relativity was extremely impressive.

Not all theorists share this point of view. Asked after a public lecture about his view of the idea of tachyons, another prominent Soviet scientist, Doctor of Physics and Mathematics Ya. A. Smorodinsky, remarked that the theoretical research in this field was utterly speculative and completely divorced from reality, that it was a kind of a theoretical game.

In short, opinions differ. But what if the tachyons did exist? They would make a third type of particles known to us. The first type includes particles which can never reach the velocity of light, i.e. almost all the known elementary particles. The second type are the photons—quanta of electromagnetic radiation—and possibly, the neutrinos, both of which propagate at the speed of light. The tachyons would always have speeds exceeding the velocity of light.

The question to be cleared is whether the tachyon hypothesis is physically feasible. The difficulty here is that certain relationships or processes which are unrealistic within the range of customary events may be realistic or feasible in another range of events. In other words, our notions of what is possible and what is impossible are relative. Only such theories can be considered physically senseless that contradict some fundamental law or laws of nature in an area where this law has been reliably authenticated. The tachyon hypothesis presents no such contradiction. The world of tachyons does not intersect our world of slower-than-light velocities in any point. The three types of particles just mentioned have one property in common: under no circumstances can particles of one type transform into another. On the other hand, we can make such an assertion only on the basis of our modern knowledge. The situation may turn out to be entirely different if it is viewed from the standpoint of deeper, as yet unknown, scientific information.

In that case we may suppose that the world of tachyons may intersect our world which will mean that processes developing in indefinite directions exist in nature. The principle of causality according to which cause always precedes effect is a fundamental postulate of physics. In other words, no events can influence the past and change what has already taken place. But in a world of particles moving with the speed of light or faster than light this principle may be upset, and cause and effect may change places, depending on the frame of reference.

In processes where signals move at faster-than-light velocities the sequence of events (which of them took place before others) depends on the choice of the coordinate system. Meanwhile the direction of the flow of information—the basis of the cause-and-effect relation—remains unchanged. This results in violations of causality.

Could a tachyon flux make it possible to transmit information into the past?

Such a flux, it is supposed, could help to create a telephone directed into the past, or make it possible for a person to shoot himself at eleven in the morning the day before... This is paradoxical but only as long as the world of slower-than-light velocities intersects that of faster-than-light velocities. If an area of only faster-than-light velocities is considered, no such paradoxes are born.

So far no experimental data have been obtained to prove the viability of the tachyons. Probably this can be explained by the fact that the experiments failed to take account of some properties of these hypothetical particles for the simple reason that they are yet unknown. The future will show if this is so.

As the physics of the microworld develops it gives rise to extraordinary notions and images shattering customary views and knowledge. It vividly demonstrates the fallacy of absolutization of existing scientific knowledge. Neither physics nor astronomy is ever likely to come to an end in their development.

The theory of elementary particles, which reveals ever more incredible events, becomes increasingly abundant in complex mathematical and other images that are without analogy in the world directly surrounding us.

It is remarkable that this theory is increasingly fused with the theory of events of a cosmic order, that the laws of nature governing the extreme points of the great universal scale—the world of microparticles and the world of cosmic events—never contradict each other.

This is graphically illustrated by gravitational phenomena. A deeper penetration into the microworld shows a considerable weakening of gravitational effects, but up to a certain point, after which their role again increases dramatically and they become the prevalent physical phenomenon, just as in the macroworld of space.

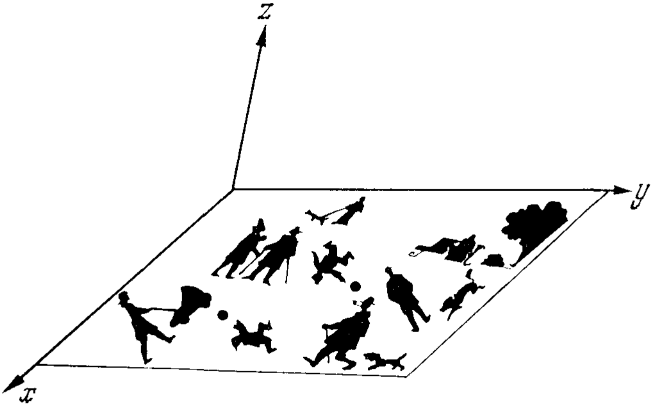
In the microworld characterized by ultrasmall distances, energy and consequently mass as well, grow in value to such an extent that in this area the microworld may encounter macroscopic and even megascopic phenomena. The two worlds merge, as it were, which is why they share some of the laws of nature. Black holes exhibiting the extreme density of matter, are another area where cosmic and microscopic events merge. Here gravitational phenomena are enormous on both levels, expressed in the first case in a changed geometry of space and in the second, in quantum-mechanical effects.

Thus it is clear that the universe conceals the clues to the understanding of both the micro and macroworlds. Small wonder, therefore, that theorists—physicists and astrophysicists—have lately concentrated their efforts on the theory of quantum gravity and of quantum cosmology. Hopefully, this will enable them to combine quantum physics explaining the microworld with the general theory of relativity working for infinitely great scales.

## What If There Are Four?

Ours is a three-dimensional world, everything in it having length, breadth and height. How would a four-dimensional world look and how would the extra dimension tell on the various physical processes?

Modern science-fiction stories often toy with the idea of the so-called "zero-transportation" or transition through a "hyper-space", "sub-space" or "supra-space" to cover great distances almost instantaneously. What is the basis, if any, for such conjectures?



wo-dimensional creatures

If we remember that the maximum speed any material body can develop is the speed of light in a vacuum and that such speed is practically unattainable, we begin to wonder why should SF authors speak of leaps through millions and hundreds of millions of light-years.

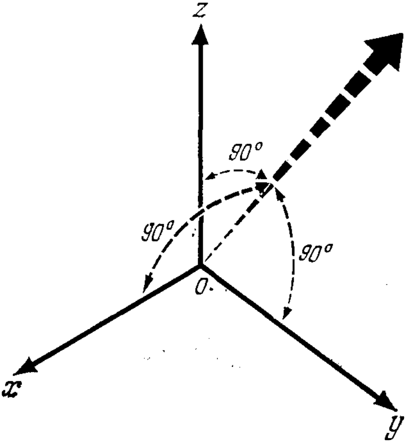
Let us imagine a one-dimensional creature—a point-living in a one-dimensional space—on a straight line. The crammed world of a straight line has only one dimension—length—and only two possible directions of motion—forwards or backwards.

Now two-dimensional creatures, "flatties", would have many more possibilities. They would be able to move in two dimensions, for their world would also have breadth. But just as the point on a straight line cannot get away from it, the two-dimensional creature cannot move into a third dimension. Theoretically, one- and two-dimensional creatures can stumble on the idea that there might exist a third dimension, but the way to it is closed for them.

On both sides of the two-dimensional plane there stretches a three-dimensional space, peopled by us, three-dimensional creatures unknown to the two-dimensional ones, isolated as they are in their two-dimensional world where they can only see within the bounds of their plane. Therefore the two-dimensional creatures could learn about the three-dimensional world and its inhabitants only if one of us would poke a hole, so to say, in the plane. But even then the two-dimensional creature would be able to observe only the two-dimensional area of contact between the finger and the plane. It would be hardly possible for it to judge about "elsewhere", a three-dimensional space and its three-dimensional population.

Now we can use the same reasoning for our three-dimensional space and imagine it being contained in some vaster, four-dimensional space, just as the two-dimensional space is contained in ours.

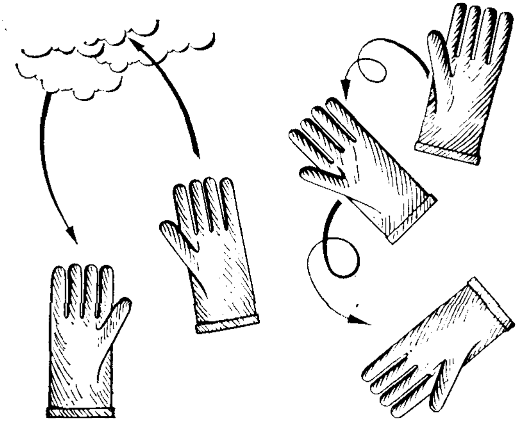
But first let us try to establish in geometrical terms what is a four-dimensional space. Our three-dimensional world is characterized by the three fundamental dimensions, perpendicular to one another—length, breadth and height (three perpendicular axes of coordinates). If it were possible for us to imagine a fourth line perpendicular to every one of the three and drawn through the same point we would then have a geometrical representation of a four-dimensional space.



The fourth dimension

Let us turn to "flatties" once more. A third dimension for them is the same as a fourth to us, with the difference that we can easily visualize their two-dimensional plane as part of our three-dimensional space and they cannot.

The two-dimensional, flat world can, in prin, ciple, have an opening into the third dimension-even though its inhabitants cannot leave their plane. This fact may, in certain cases, give rise to processes that could not have occurred, had there been no third dimension.



Experiment with a glove

Let us take a simple clock-dial drawn on a plane. No matter how hard we try to turn it to make the figures on it go counterclockwise, we'll never be able to do it while ourselves remaining in that plane. We'll succeed only if we "extract" the dial from the plane into the three-dimensional space, turn it over and then return it to the plane.

In the three-dimensional space this point could be illustrated by the following experiment. Can we make a right-hand glove good for the left hand just by moving it in our space without turning it inside out? Clearly, we cannot, for that we need a fourth geometrical dimension.

We do not know a way into a fourth dimension. A fourth dimension would offer amazing opportunities if we knew the exit into it.

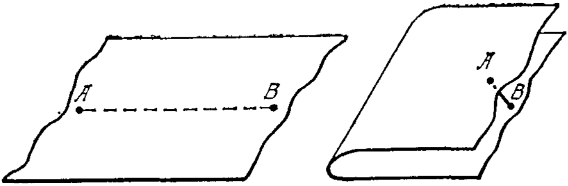
Again this point could be illustrated by a trip to the two-dimensional world. Let us try to imagine that our two-dimensional "flatty" has to cover a distance of 50 kilometres between some two points on the plane. If it moves at a speed of one metre a day, the journey will take it more than a hundred years. But if the two-dimensional plane were bent in a third dimension, the distance between the two points would only be one metre, and the creature would need only one day to cover it. But that metre lies in the third dimension. If it managed to cross it, it would amount to what is termed "zero-transportation" or "hyper-transition".

The same situation could be created in a curved three-dimensional world.

As indicated by the general theory of relativity, our world is indeed curved. In a four-dimensional world embracing our three-dimensional space to cover a great cosmic distance it would only be necessary to "jump" over the "fourth-dimension crack" separating the two worlds. This is what SF writers mean when speaking of "zero-transportation".

So much for the enticing advantages of a fourth dimension. But it also has some "drawbacks".

It has been found that motion becomes less steady with increase in the number of geometrical dimensions. Extensive research data point to the fact that in a two-dimensional space no force can upset equilibrium and push a body moving along a closed trajectory round another body into infinity. In the three-dimensional space the situation is not quite so rigid but here, too, the trajectory of a moving body does not unbend into infinity, unless the perturbing force is too great.



Geometrical interpretation of the fantastic "zero-transportation"

The theory of transformations, an important department of geometry having both theoretical and practical significance, deals with changes in geometric figures affected by transformation of coordinate systems. If the transformed geometric figure retains its angles, the transformation is called conformal.

To illustrate. Let us draw an arbitrary coordinate network ("skeleton") on a simple geometric figure, a square or a polygon. If the figure changes into any other figure while retaining its angles as a result of transformation of the coordinate system, then it is termed conformal. The transfer of the surface of the globe onto a plane (used in map charting) is an example of conformal transformation.

As early as the last century the German mathematician Bernhardt Riemann was able to prove that any whole, flat figure (without holes, continuous) could be conformally transformed into a circle. But soon Riemann's contemporary, the French mathematician Joseph Liouville, proved that not any three-dimensional body could be conformally transformed into a sphere.

Thus, in the three-dimensional space the possibilities of conformal transformations are not as extensive as on a plane. An addition of only one axis of coordinates limits the geometric properties of space considerably. Is this fact not, perhaps, an explanation why our space is geometrically three-dimensional and not two- or five-dimensional? Could it be so because a two-dimensional space is too "free" and a five-dimensional one is too "rigid"?

Scientists have tried to answer this question on the basis of general philosophical considerations. Aristotle asserted that the world should be perfect and only three dimensions could guarantee such perfection.

But physics cannot take this argument for an answer. Galileo did something more concrete in this line when he postulated that there could exist no more than three mutually perpendicular directions in our world. However, he did not try to establish the reasons. The well-known German mathematician Gotfried Leibnitz attempted to find an answer by means of purely geometrical methods. His proof was not very convincing though because it was based on abstract speculation removed from the external world.

The number of dimensions is a physical property of real space and it must have definite physical reasons, and be a consequence of fundamental physical laws. Why this is so could probably be explained in the context of a more general physical theory.

There is one more question to consider. The theory of relativity speaks of the four-dimensional space of the universe. But it is not exactly the four-dimensional space which we have been discussing, since the fourth dimension in it is time. Apart from establishing the intimate connections between space and matter, the theory of relativity also established one between matter and time, or, between space and time. Since time is impalpable, it is hard to construct a model of a four-dimensional space, in which three dimensions are of space and one of time, that is, to represent graphically what the theory of relativity refers to as space-time continuum or simply space-time. In order to describe the staggering reaches of the universe beyond our solar system we must visualize it as a continuum in three dimensions of space and one of time. We are accustomed to separate these dimensions and are aware of space and of time separately. But an objective description of the universe cannot detach the time dimension from the space dimension any more than length can be detached from breadth and thickness in an accurate representation of a house, a tree, and so on. According to the outstanding German mathematician, Herman Minkowski, who developed the mathematics of the space-time continuum as a convenient way of expressing the principles of relativity, "...space and time separately have vanished into the merest shadows, and only a sort of combination of the two preserves any reality."

When we contemplate the stars and realize what vast distances separate us from them, we immediately see the intimate connection between space and time. Millions and billions of years would be required to reach them, unless faster-than-light speeds could be developed. But according to modern physics, which is closely related to the theory of relativity, the speed of light is a barrier that cannot be exceeded under any circumstances. Perhaps in decades or centuries to come scientists will discover new theories that will permit faster-than-light space travel. This would constitute a revolution more profound and far-reaching than anything that has ever occurred in science.

It is clear, therefore that "zero-transportation" and other such ideas cannot overstep the confines of science fiction, at least at the present stage of scientific development.

## In a Shrinking Universe

As we have mentioned, our region of the universe, the Metagalaxy, is expanding and the farther a galaxy is away from us, the faster it is receding. However, the equations of the theory of relativity permit of a shrinking universe as well. Does the fact that the Metagalaxy is expanding and not shrinking have any major significance? What would change in the external world if the Metagalaxy were shrinking?

It might seem, at first glance that nothing much would happen. No one would be likely to notice anything, except astronomers who would be watching a violet and not a red shift, since the galaxies are separated from the earth by distances measured in millions and billions of light-years.

The situation is much more involved, though. Let us start by asking what may seem a naive question: why is it dark at night? This is a question which has played quite a part in the development of scientific cognition of the universe and which is referred to in astronomy as the photometric paradox.

It is like this. Since the stars are scattered all over the universe and all of them emit roughly the same amount of light, then no matter whether grouped in galaxies or not, they should be covering the whole celestial sphere with bright disks of their light, as the Metagalaxy contains billions upon billions of stars. In other words, every area of the sky should be as bright as the sun disk for in this situation visible luminosity does not depend on distance. A dazzling, hot flux of light should be flooding the earth, and its luminosity should be commensurate to about 6 000 degrees, which is nearly 200 000 times as luminous as solar light. But the sky at night is black and cold. Why?

In the past attempts were made to attribute the photometric paradox to absorption of light by interstellar matter. But in 1937, the Soviet astronomer Vasili Fesenkov showed that this explanation was no good, because interstellar matter does not so much absorb light as scatters, which means that the problem is even more involved.

The theory of the expanding Metagalaxy is the only one that removes the photometric paradox automatically. Since the galaxies are receding, there is the red spectral shift to be observed which means that the frequency, hence, the energy of every photon, decreases (the red shift, as we know, is the shift of electromagnetic radiation to the longer frequency range). And the longer the wave, the smaller the energy of radiation, and the farther the galaxy. The greater the red shift, the less intensive the energy of every coming photon.

Furthermore, the continuously growing distance between the earth and a receding galaxy causes every successive photon to travel a slightly greater distance than the preceding one. Owing to this fact, the photons do not come to the receiving end as often as they are emitted by the source. Hence, the number of the photons coming to earth per unit time grows smaller, which also cuts the level of energy brought per unit time. Thus the red shift indicates a weakening of the radiation of every galaxy. The radiation is not only displaced to the low-frequency range but it also loses some of its energy. That is why the sky is dark at night.

Now we can answer the question as to what would happen if the Metagalaxy were shrinking. If this process were going on for billions of years, we would be observing a violet and not a red shift and it would be directed to the high-frequency range, and brightness of the sky would be greater. Then there could be no life in our area of the universe. Obviously, it is not accidental that we exist in an expanding Metagalaxy and observe the red shift. As A. L. Zelmanov cleverly put it, we are witnessing processes of a definite kind, because other processes occur without witnesses. There can be no life at the earlier stages of the expansion and the last stages of compression.

## Space Mirages

An extraordinary space object, a double quasar, was discovered in the constellation of Ursa Major in the middle of 1979. The two quasars are situated at a small angular distance from each other which corresponds to the actual distance of only 500 light-years. It has been registered under the index Q 0957+561 A, B. Q stands for quasar, the figures are the celestial coordinates and the letters A and B show that it is a binary object.

The short distance between them is in itself an amazing fact since quasars are distributed more or less evenly and are considerable distances apart. Even more amazing is that the two objects look as much alike as twins. Their spectra are identical, hence the chemical composition, and even the intensity of individual spectral lines. Furthermore, their spectra are also identical in the ultraviolet region. Both quasars are receding from the earth with the same speed—about 0.7 of the speed of light, which means that the objects are not simply projected on the same area of the celestial sphere but are situated at exactly the same distance of the order of 10 billion light-years from earth.

How is the binary quasar to be interpreted? Is it a coincidence unique in nature? But the probability of coincidences in nature is extremely small. Could it be that in reality there is no such quasar at all and this is simply an illusion, something like a cosmic *mirage*?

There is nothing surprising about such a proposition. As far back as in 1916 Einstein suggested on the basis of his general theory of relativity that light rays could be deflected in the gravitational fields of massive space objects. His suggestion was brilliantly confirmed by data obtained during the total solar eclipse of May 29, 1919.

In more recent times, basing their research on Einstein's discovery, theorists arrived at the conclusion that supermassive bodies (especially supermassive black holes) must not only deflect light rays but also focus them and thus play the role of what they termed gravitational lens. For example, if two stars are situated on the same line of vision, i.e. one closer to observer and the other farther away, then the gravitational field of the closer star may focus the light of the distant star as a result of which the brightness of the former will be much more intense.

The discovery of quasars with their extraordinarily powerful emission exceeding anything hitherto observed prompted some astronomers to explain them not on the basis of their inherent properties but by the action of gravitational lenses situated in outer space. Further studies showed, however, that quasars were indeed superpowerful sources of energy which had nothing to do with gravitational lenses.

This does not mean to say that the deflection of light in strong gravitational fields cannot give rise to illusions. The discovery of a binary quasar revived the interest in this issue. Let us imagine that a compact massive body—a massive black hole or a galaxy—is situated between some space object, say a quasar, and the earth.

But for this body, the quasar's light rays travelling along straight lines would create an ordinary image of it. The presence of a massive body on the way would change the picture considerably. Affected by the strong gravitational field, the beams of light would have been deflected and the observer would not see the quasar in its usual place. What he would see would be light rays which would have orbited the gravitational lens from left and right, not unlike a water stream flowing around an obstacle on the way, and would create not one (primary) image of the quasar, but two imaginary (secondary) ones separated by some distance. The secondary images would be situated on the tangents to the bent light rays received by the observer. In other words, the physical nature of this phenomenon would be similar to that causing mirages in open spaces in terrestrial conditions.

It has been shown theoretically that more complicated, multiple images may be created depending on the relative positions of the object being observed, the gravitational lens and the earth-based observer.

But back to the double quasar discovered in Ursa Major. Is it a real object or an optical illusion? According to calculations, the light rays creating a double image after they have been split by the gravitational lens, must cover different distances on their way to the observer. This means that one of them will reach earth somewhat later than the other.

The delay in the arrival of the light rays circling the gravitational lens is also to be explained on the basis of one of the postulates of the general theory of relativity—the retardation of time in strong gravitational fields. In the case of a gravitational lens this retardation causes an additional "braking" of electromagnetic signals. If the double object in question is really a cosmic illusion then all the changes taking place in one of its components must be repeated in the other in a strict sequence and at definite time intervals. If all the changes observed will reoccur after the same lapse of time, the hypotheses concerning the splitting of light rays and emergence of cosmic mirages will receive serious evidence in its favour.

Observations in 1980 by means of the 6-metre telescope of the Special Astrophysical Observatory of the USSR Academy of Sciences showed that the brightness of the A component is gradually weakening and that of the B component increasing.

It was further established that similar changes could be detected in the radio and ultraviolet regions. This seems to suggest that the duality of the quasar is really an optical illusion. The question can be settled conclusively only on the basis of further studies.

Theorists have calculated that the expected time lapse in the observations of the A and B components should be five to six years, which means that it will be possible to judge if the changes in them coincide in the near future.

In the meantime the "pro" and "con" arguments are being considered. One of the cons is based on the fact that it was found during the observations that the A component was redder than the B component, and also that the radio images obtained by radiointerferometric studies showed the mysterious pair to be different in structure.

Astronomers at the Mount Palomar Observatory have been able to explain these differences more or less conclusively. The data they obtained by means of the 5-metre telescope equipped with special TV imaging and computing devices showed that in red light the B component was slightly more extended than the A component. Their conclusion was that the B component merged with the galaxy playing the role of the gravitational lens and this distorted its outlines. By "subtracting" the A component from the B component they obtained the part of the B component which probably is the gravitational lens-galaxy.

If this is really the case then, as has been measured, its angular separation from the B component is only 0.8 second of arc. Consequently, the component B emission travels through the medium of the lens-galaxy, owing to which the emission of the B component in the red band is augmented by the red emission of the stars within the lens-galaxy.

So much for the probable explanation of the difference in the brightness of the A and B components in the binary quasar in the light of the gravitational lens hypothesis.

The creation of illusions may follow a different scheme. If the object which is the gravitational lens has great mass (e.g. a massive black hole) it can not only deflect light rays from some luminary, but also turn them a considerable angular distance away from their original path and create a curious illusion.

The ray of light coming from a star situated some distance to one side of the black hole will circle the hole, and when we on earth see it the star will be situated on an extension of this light ray, that is, exactly in the direction of the black hole acting as a gravitational lens. The same can happen to the light coming from many other stars. Having been deflected to varying degrees in the region of the black hole the light rays will meet and create an image of an extremely bright object, although in reality there is a black hole in the place of this object, which radiates nothing at all.

One may naturally wonder if the quasars in general are not one of the forms of optical illusion in space created by the focusing of starlight by black holes.

Another question is: What will the observer see if the black hole is situated exactly between the earth and the star he observes?

In this case not only gravitationally deflected rays will reach the earth but also numerous other rays that have orbited the black hole one or several times before managing to break out of its gravitational field. Theorists predict that an earthbound observer will see the star as an array of numerous concentric bright rings merged into one object owing to the great distance and seeming much brighter than in reality.

Now picture a situation where a star in its motion around the centre of the Galaxy appears at a certain moment on an imaginary line between the earth and a black hole. It will be seen as described above, i.e. as a superbright space object. It will flare up, as it were, and then will return to its former state. Such a picture will be conspicuously like the well-known phenomenon of supernova explosion.

It goes without saying though that both the quasars and supernovas are perfectly real physical objects observed in space. In the case of the quasars, a whole range of physical events makes it *impossible to include these objects in the category* of purely optical effects. As for the supernovas, the gaseous nebulas—remnants of matter ejected by a star—observed in their vicinity are convincing evidence in favour of their existence.

Then what is the sense in discussing cosmic illusions at all? The point is, however, that if the optical effects described above are a theoretical possibility then they can probably be created in reality under certain conditions. It must not be ruled out that some phenomena observed in the universe may somehow be connected with gravitational lenses.

Theorists believe that gravitational lenses must possess some unusual properties as compared with ordinary lenses. The apparent brightness of a space object, for instance, will increase and not decrease as the distance between the lens and the observer increases. Besides, a gravitational lense does not have a definite focal length, owing to which it does not focus rays in one point but on the surface of a cone beginning at some minimal distance from the lens and extending into infinity.

An observer stationed outside such a cone will see only the really existing object in the direction it is really situated. If the observer is inside the cone he will see at least three images of the object. Moreover, if the gravitational lense has a certain structure, the number of images will be five or more.

Then why in the case of the binary quasar Q 0957+561 A, B are only two images seen? If the duality of this object is really an illusion created by the gravitational bending of light rays, the observer should see three images, as theorists claim. Some of them explain this discrepancy by proposing that the third component merges either with the B component or with the galaxy which is the gravitational lens.

This theory naturally can be confirmed in practice only up to a point. In the first place it allows for certain simplifications in the calculations it is based on and in the second, the rays passing through a gravitational lens are also affected by the gravitational fields of other objects.

The remarkable feature about gravitational lenses is that their action on electromagnetic radiation does not depend on the length of the waves, i.e. they focus visible light as well as radiowaves, ultraviolet, X-ray and gamma radiations.

The modern picture of the observable portion of the material world—our universe—is a sphere filled with galaxies, quasars, and other space objects. The recession of galaxies causes the radius of this sphere to increase at a fast rate.

Our ideas about the location of space objects, however, rest on the assumption that the electromagnetic radiation, visible light included, travels in straight lines. On the other hand, our universe is not empty but harbours objects with different masses. But according to the general theory of relativity mass warps space, consequently the paths followed by the electromagnetic radiation cannot be straight. This means that the objects we observe from earth may be situated not where we see them. And the greater the distance between the observer and the object observed the greater the difference between the apparent and real positions of this object.

In reality the geometry of the universe may turn out to be extremely complex and the paths of light rays may be quite confusing as well. According to some hypotheses, light rays can reach an earth-based observer not from space objects directly but after orbiting all the space of the universe several times. What the observer sees as a result is something like one would see if stationed between two parallel mirrors facing each other—an infinite row of identical images. In other words, one and the same space object may be seen from earth as a series of similar objects, of which only the one closest to us exists in reality and the rest are imaginary. Such images have been given the expressive name "ghosts".

It must be emphasized once more that all this is only a theoretical possibility and there is no way of saying if it will ever be confirmed. A thorough study and comparison of known space objects has shown that up to a distance of 30 million light-years there are no chains of identical images. If this is true also for great distances is yet to be seen.

The binary quasar cannot be part of such a chain either, for its two components are equidistant from the earth, and what is even more important, their luminosity is of equal intensity. As for the "ghosts" they must be created by rays which have travelled such different paths that they cannot be of the same brightness.

One intriguing possibility offered by gravitational lenses (if they really exist) is the verification of Hubble's constant, characterizing the rate of expansion of the universe. Observations show that the speed of mutual recession of the galaxies is proportional to the distance between them, or to put it in another way, the farther a galaxy from the earth, the faster it is receding. Hubble's constant is the ratio of the distance between the local group of galaxies (our Galaxy among them) and a receding cluster of galaxies to the rate at which the distant cluster recedes.

Hubble's constant is very difficult to determine accurately because there is no way of measuring the exact distances to remote galaxies. Small wonder therefore that the value of Hubble's constant has been revised many times. Only recently it was considered to be about 100 kilometres per second per megaparsec.[1] Then it was reduced to

---

[1] *Parsec*, an astronomical unit of distance equal to 30.8 × $10^{12}$ km, one *megaparsec* equals one million parsecs.

a half of this value and quite recently has been again restored to its former value by French astronomers on the basis of vast data obtained from observations of galaxies.

If this latter value agrees with reality then all the cosmic distances must be revised and reduced correspondingly, which also means that the age of the universe (from the moment of the big bang and the beginning of expansion to the present time) must also be revised.

The very fact that Hubble's constant has been given varying values proves that modern means of determining it are inadequate.

Of what help can gravitational lenses be in this respect? If further observations make it possible to determine the value of the delay in the arrival of a light ray bent by a gravitational lens, then it will be possible to calculate the time it takes for a straight ray to reach the observer on earth, hence to determine the exact distance to the object being observed. If this distance is known and the amount of the red shift in the object's spectrum is determined then Hubble's constant can be calculated on this basis.

Finally, on the basis of the known delay in the arrival of a bent ray it will also be possible to calculate the true mass of the galaxy acting as a gravitational lens and thus determine if neutrinos make a substantial contribution to this mass.

It should be mentioned in conclusion that two very weak objects have been discovered in the vicinity of the quasar PC 1115-08, whose spectra are similar to that of the quasar. This is probably another illusion created by a gravitational lens.

Other objects of a similar nature have been detected as well.

### Had It Been Foreseen (science fiction)

Barkalov was driving as fast as the winding mountain road would allow him. Finally the last bend was behind and the road plunged into the valley cut in two by a railway track as straight as a ray of light. Barkalov pressed the gas pedal hard and the car shot ahead onto the even stretch of the motor-road running alongside the railway. He could feel the hot puffing of the passenger express train gaining on him.

Then came the rumbling noise of a distant avalanche. He slowed down and listened. The noise began to subside and he could tell its source was somewhere ahead and to the right of the road.

"Funny," Barkalov was thinking. "This avalanche can really do no harm to the tracks, it's too far away. Maybe the prediction is just a harmless theoretical trick having nothing to do with reality. On the other hand, the avalanche has really happened. And right on the dot. The probability of a coincidence is infinitesimal..."

...After the seminar Academician Matveyev found Barkalov in the canteen.

"I've almost missed you," he said in a somewhat unsteady voice. "I know you are in an awful hurry, but I beg you, Sergei Nikolayevich, to step into my office for a minute."

Indeed Barkalov was in a hurry: he had a ticket in his pocket for the Southern Express which was to take him to the institute's observatory where astronomers were going to check out Barkalov's new theory. Less than two hours remained before departure, there were several things to attend to and Barkalov was in no mood for delay. He was on the point of refusing Matveyev, pleading pressure of time, but did not, puzzled by the tremour in the Academician's voice and a vague expression of uneasiness on his face. Another thing that puzzled him was that the Academician had addressed him by his first name and patronymic—he had never bothered about it before. On top of everything else Academician Matveyev was a scientist of world renown, the author of numerous outstanding ideas and Barkalov considered himself to be his pupil. So, instead of refusing politely, he rose from the table, leaving his coffee unfinished, and followed Matveyev.

In the second-floor corridor the Academician let the younger man pass ahead and took him by the elbow as though afraid to lose him. Barkalov was becoming really bewildered.

When they reached Matveyev's office Barkalov thought he heard Matveyev breathe a sigh of relief. Seating his guest in an armchair, the Academician took a seat opposite him.

"I heard your report recently, Sergei Nikolayevich, in which you outlined the basis of your mathematical theory", he began without preliminaries, "and I would like to tell you I believe your work is outstanding. You are very talented, Sergei Nikolayevich. I can see this theory promises to reveal fundamentally new possibilities in mathematics, and moreover, it is going to produce a great impact on physics."

Barkalov could not believe his ears. What Matveyev was saying was simply extraordinary.

He had never praised anyone to his face. What he was more likely to do—and he did it quite often—was to give one a good dressing-down, freely and uncompromisingly. But to praise anyone—Barkalov could not remember such a thing ever happen.

"And you must see your work to the end," continued Matveyev.

"This is precisely what I'm doing", Barkalov muttered in confusion.

Matveyev was silent for a moment and, leaning forward a little, looked closely at Barkalov:

"And this is why, dear Sergei Nikolayevich, you must... take care of yourself."

"I don't understand a thing!" Barkalov exclaimed.

"You know, as they used to say in the old days, God takes care of those who take care of themselves."

"Please forgive me Rostislav Valerianovich, but you are talking in riddles," Barkalov was beginning to lose his temper. "Do you mean to say you know something about me that I myself don't know?"

"That's it. Exactly."

"Then tell me, for God's sake!" Barkalov said impatiently, stealing an anxious look at his wristwatch.

"That's the point. It can't be done so simply." He jumped from the armchair and began pacing the room. "You must be familiar with the hypothesis about the time cycles of the universe?"

"The idea of perpetual recurrence? Schopenhauer and Nietzche?"

"Not only them. In Einstein's time Kurt Gödel built a model of the universe in which timelike geodesic lines are closed. In his universe everything recurs periodically."

"But if I'm not mistaken, Einstein was not very enthusiastic about Gödel's idea."

"Their contemporaries vary on this, but that's not important," Matveyev remarked.

"As far as I can remember," Barkalov continued, "Chandrasekhar subsequently showed that Gödel's closed trajectories should be discarded on the basis of physical sense."

"Oh no, my dear friend," Matveyev objected, "such argumentation is worthless. What do you mean by physical sense? It can be interpreted this way and that."

"What are you driving at?" Barkalov asked suspiciously.

"Gödel's model is unviable, naturally. Chandrasekhar is correct as far as this is concerned. But this does not rule out the possibility of cyclic models in general."

"Have you made any progress in this area?" asked Barkalov intrigued.

"Yes, yes, I have something, a model," mumbled the Academician without enthusiasm.

"It's very interesting," Barkalov looked at his watch again.

This time Matveyev noticed his look.

"In a hurry? It's useless. Sooner or later the universe is bound to return to this moment."

"Are you serious?" Barkalov was amazed. "A theoretical model, even a logical one, is one thing but it's quite another..."

"When you come to reality? Is that what you wanted to say? Come with me."

Not looking at Barkalov the Academician crossed the room and disappeared in the door behind his desk. Barkalov had no choice but to follow him. They passed through a narrow corridor, through thick lead-protected doors and found themselves in a spacious hall crammed full with equipment.

The Academician stopped at a control panel complete with numerous display screens and looked at his guest expectantly.

"Quite something, I must admit! But I'd like to remind you that I'm a pure mathematician and do not understand the first thing about all this technology. Besides, I must warn you that there is an anecdote circulating all over the place about me just as in the case of young Pauli: they say that the minute I poke my head into a laboratory all instruments break down. So be careful, Rostislav Valerianovich!"

"This is no longer important," Matveyev said in a queer voice. "They've all done their job already". Giving Barkalov no chance to grasp the meaning of his words, he went on:

"You are going somewhere, Sergei Nikolayevich. I'm asking you in all seriousness to cancel your trip."

"But why?" Barkalov began automatically and stopped short: how could Matveyev know he was going anywhere?"

"Why? Can you trust my word?"

"I beg you to forgive me, Rostislav Valerianovich, but I've never believed in witchcraft."

"But you are going somewhere, aren't you?"

"I'm making no secret of my plans. I'm leaving in about an hour's time."

"By train? In a southerly direction?"

"Rostislav Valerianovich, if you are up to something on my account.."

"Please answer my question," the Academician demanded.

"Yes, by train, to the south," Barkalov replied keeping his temper with effort.

"Listen, my dear friend, you are not going anywhere," Matveyev said in an uncompromising voice.

"What's all this about, Rostislav Valerianovich?" Barkalov exploded finally. "You catch hold of me in the canteen, bring me here almost by force, start a conversation about cyclic models, then demonstrate an obscure piece of machinery, and on top of all this, have the nerve to demand I should give up my trip. Don't you think it's slightly unorthodox, to say the least?"

"Mm-m, yes," Matveyev sighed. "So you want explanations. Just the thing I wanted to avoid."

"But, Rostislav Valerianovich, if this concerns me, can't I know what it is?"

"In some cases it's better not to know."

"To hear such a thing from you of all people! Another riddle! Too many riddles all round, don't you think?"

"You've just said something about witchcraft. What has come to my knowledge is also witchcraft if you like. Do I look like a prophet?" Matveyev forced a smile but his eyes remained serious.

"Now then, my dear Sergei Nikolayevich," Matveyev went on, "Have you ever heard of self-organizing predictions? Some come true just because they were made. Do you remember the tale of Oedipus and what an oracle foretold him? I have no desire for my oracle to come true. Do you still want to know?"

"Undoubtedly, since you've started let's get it over with," Barkalov replied firmly.

"OK then, listen. If you do not give up your trip you are in for a lot of trouble, in other words, you'll die..."

Barkalov started. A cold shiver passed down his spine.

"What nonsense!" he muttered. "How do you know?"

Matveyev nodded in the direction of the control panel:

"I saw.."

"Wait! Do you mean to say?..." Barkalov paled.

"Yes. This device has enabled us to peer into the previous cycle in the vicinity of the respective point in space-time. We tried to scan in all the coordinates, but the machine is not yet good enough and the images were vague. But still we could see a thing or two."

"Including your prediction?"

"How else would I have known you were going away, and moreover, that it was going to be a south-bound train?"

"Can you show me the video-tape?"

"Do you think you should see it? It isn't so pleasant to see one's own... you know what I mean."

"I must see," Barkalov insisted.

"All right," Matveyev conceded in a tired voice, "look at the screen," and he pressed a button on the panel.

The matted surface of the screen disappeared beneath clouds of blue and pink mist. When the mist lifted Barkalov was looking into an opening to a different and yet familiar world.

He recognized the conference hall in his institute where some sort of gathering was taking place. He saw several people he knew among the blurred shapes at the presidium table on the stage. Then the image moved away and it was impossible to see anything. When the screen cleared once more Barkalov saw mountains and valleys which were falling from view fast on both sides of the screen—a train was speeding across a mountain valley. Then there were more mountains and then all disappeared in clouds of dust, tumbling boulders and raining earth. It was an avalanche. Great hunks of rock were falling from above, hitting a mountain slope, dislodging more hunks and rolling down into the valley. For some time after that the screen showed nothing but interference, but when it stopped Barkalov saw the terrible scene of a railway catastrophe: misshapen, telescoped carriages, twisted tracks, the ruined embankment and scattered bodies...

Matveyev pressed another button and the image froze. Barkalov had his face almost pressed to the screen. He saw himself or his twin in the centre of the still, a lifeless body with outstretched arms, at the edge of the embankment crushed by an overturned carriage.

"When... was it?" Barkalov managed to whisper and immediately realized the absurdity of his question.

But Matveyev answered in an unruffled, academic voice:

"Something like thirty or forty billion years ago."

"Are you saying I have lived many times over already?" Barkalov asked, completely shaken.

"Yes indeed, and quite probably countless times."

Although Barkalov was a mathematician used to dealing with most mind-wrenching abstractions, at that moment he could not think straight. Perhaps it was because of the shock of his realization that one such abstraction had turned out to be cruelly and inexorably real. And also, because that reality immediately concerned himself.

To collect his wits about him he had to comprehend the situation somehow, to find some link with things ordinary and familiar, something that would help him get back on his feet.

"How does one get used to the idea that one has lived many times before? I don't think I'm the only one, but I've never heard anyone mention such an experience."

"You may be wrong on that," Matveyev argued, "it may well be that there have been messages from the past but we have been powerless to recognize them."

"Well, well," Barkalov was incredulous and depressed. "Does it follow that I've been killed in a railroad accident several times?"

Matveyev shrugged and said something under his breath. They were silent for a while. The Academician was watching the young scientist anxiously, but the latter had soon recovered sufficiently to be able to think reasonably.

"It is said that he who is born to be hanged, shall never be drowned. Evidently that's how it really is. We go through the same things many times like actors playing one and the same scene."

"But there is also another thing said," Matveyev spoke with emphasis. "If it were possible to know what was going to happen many unpleasant events could be prevented. That is why people used to go to various astrologers and fortune-tellers. Alas, they could tell nothing about the future."

"But now we have an oracle here who can read future in the past. Have you thought about what our life is going to be now that we will know everything about it beforehand?"

"It's not everything we will be able to know beforehand. We can obtain information only about events happening in the immediate vicinity of the point in the space-time of the previous cycle which corresponds to the moment of observation. But still we can have some preceding knowledge of the future."

"But what's the sense?"

"Really, Barkalov, you surprise me," remarked Matveyev dryly. "With your pre-knowledge of what is going to happen to the Southern Express, you can stay home. Simple as that!"

"I haven't thought about it," Barkalov admitted "But could my action cause a paradox of some kind which would mean the end of the universe, God forbid?".

"In the model we have built, the authenticity of which, as you have just seen, can be proved by experiment, world lines are subject to statistical laws. You know perfectly well that in areas where probability prevails considerable deviations from mean values are possible."

"Does this mean the course of evolution of the universe is not quite identical in all its time cycles?"

"No, not quite."

"Have you tried to establish the nature of these deviations? What causes them? Fluctuations?"

"Chance disturbances are not significant. Computations show that natural disturbances are 'erased' pretty soon."

Matveyev was speaking in a deliberately nonchalant tone he usually used when he answered questions after reading a paper. It was plain that his idea was to channel the conversation into some abstract area, so as to relieve the impression his prediction had produced on Barkalov.

"Natural disturbances did you say?" Barkalov echoed the Academician's words, puzzled. "But I don't understand, can there be others?"

"As far as we have been able to judge, lasting deviations from the world lines occur only in those regions of space-time where a drastic decrease in entropy is observed, an extremely unlikely prospect within the framework of purely natural processes".

"I must have grown considerably dumber over the past hour," Barkalov said with a slight smile. "I still don't understand what you are saying."

"I mean that only intelligent beings can create situations causing drastic decreases in the entropy of a definite area. You and me, in this case."

"Ah, I see now. In other words, I'm lucky. Thanks to your theory and your machine there is a chance for me to save myself?"

"You have already saved yourself," Matveyev smiled expansively. "The train left twenty minutes ago."

"Left! But it's full of people!"

Matveyev grew pale.

"Imagine, I completely forgot about this side of the matter. All my thoughts were concentrated on you and it never occurred to me you were not the only one."

"Can you show me the exact geographical location of the area of the catastrophe?"

"With a margin of up to 300 kilometres across. Look at the map here. The centre of the area is the 37th-kilometre crossing."

"There's still time!"

"Sergei Nikolayevich, jump into your car, quick, and drive to the railway station—to the head dispatcher—as fast as you can. Meanwhile I'll try to make use of our own channels."

Another half-hour had passed before Barkalov reached the head dispatcher. He had decided on the way that he would not tell the man anything about the cyclic models since it would be impossible for one without special training to understand anything at such short notice. So he simply told him that they had a warning at their institute that an avalanche was expected in the region through which the Southern Express would be passing and asked him to stop the train before it reached the danger area.

"I've already received a phone call from your Academician, but I assure you there is no cause for worry. The tracks were laid at a safe distance from the mountain chain. Look at the map."

"Really," Barkalov was thinking, "no avalanche, however big, can cover such a distance."

"And what did the Academician say?" he asked.

"He said he was going to speak to people higher up. But so far there hasn't been any signal. But even if there has..."

"What then?"

"You see we have no way of communicating with the Southern Express. It's being steered by an automatic control device—the route is simple. So we can't transmit any order anyway."

"But it's impossible!"

"Please believe me, the system is absolutely reliable. There hasn't been a single incident in all the twelve years it's been in operation. The possibility of a catastrophe is practically ruled out."

"And theoretically?"

"Well, unless the skies split open..."

"And if they do?"

"But you must know no one is one-hundred-per-cent safe even in one's own flat. There's always an element of risk."

"I'm wasting my time here," Barkalov was thinking, "I must go after the train in my car. If I put my all into it I'll just manage to overtake it at the edge of the danger zone. And then, I'll see..."

"We could send a helicopter, of course," the head dispatcher continued, "but it's only good for observations. The train cannot be manipulated from outside, as I've already told you. But its computer is capable of evaluating any situation by itself..."

Barkalov was not listening. He was anxiously studying the huge map of the railway network which was hanging on the opposite wall, trying to memorize the route of the motor-road. Then he ran into the street, jumped into his car, pressed on the gas and shot ahead.

...Then came the rumbling noise of a distant avalanche. He slowed down and listened. The noise began to subside and he could tell its source was somewhere ahead and to the right of the road.

"Funny," Barkalov was thinking. "This avalanche can really do no harm to the tracks, it's too far away."

The road zigzagged and Barkalov had a glimpse of the track behind. For a fleeting moment he saw three headlights of the express train speeding after him in the blue dusk, the train which should have been carrying him had it not been for what had happened during the last couple of hours...

He looked ahead to where the mountains were outlined darkly in the bluish distance. The geography looked familiar to him.

He was driving as fast as he could, so that the train would not gain on him. If he saw something dangerous ahead he would have a few seconds to decide on what to do. True, he could not even imagine what could be done in such a situation but his fear for all those unsuspecting people on the train was pushing him ahead.

He noticed a road sign on his right—a crossing. He had to slow down and then stop altogether: the barrier was down.

The crossing was over a side track going to the right from the trunk line. The position of the barrier immediately alarmed Barkalov. Since a train was coming along the main track, nothing should come from the side. In this situation the barrier closing the motor road and leaving open the side track looked preposterous.

Barkalov heard a humming sound overhead. It grew louder as a helicopter zoomed above the car sending a blast of hot air down onto its roof.

"Academician Matveyev", guessed Barkalov and the same moment saw something that almost stopped his heart. Blood was hammering in his temples: three freight cars were rolling downhill along the side track.

"That's what it is!" the thought raced through Barkalov's mind. Far away up in the mountains the avalanche must have damaged a goods train and three cars were now approaching the trunk line gaining speed on the sloping road with every second.

Barkalov glanced at the lights of the oncoming passenger train and clearly saw in his mind's eye what was going to happen in just under a minute. The cars would be at the trunk line exactly the moment the express train reached the crossing. A side blow and... the TV picture stood clear and real before Barkalov: a jumble of broken cars and scattered bodies...

This was just that extraordinary case where automatics was useless. If the freight train had a locomotive full of electronic equipment, it would have stopped on getting the signal that the trunk line was busy... But the cars detached from the rest of the train could not be controlled. And from the standpoint of the passenger train's controls everything was in order: such a situation could never have been programmed.

The helicopter returned, having circled once above the crossing. Apparently, the pilot realized the grave implications of the situation.

"But you can't do anything from a helicopter," Barkalov remembered the head dispatcher's words.

Meanwhile the distance between the passenger express headlights and the freight cars was shrinking mercilessly. It was clear that the train would not be able to pass through the crossing before the freight cars. Barkalov was desperately seeking a way out.

His decision was ready the moment the dark shapes of the freight cars had noiselessly emerged almost abreast of his car. He pressed on the gas all the way and the car lunged onto the crossing, throwing the striped arrow of the barrier aside and blocking the track. The driver had remained at the wheel...

The evening silence was broken by the screeching and crunching sound of metal being smashed. The heavy freight cars were still rolling, but the momentum was gone. And when they reached the main track pushing before them what only seconds back was a fast car, the passenger train had already passed through. The catastrophe which had previously occurred countless times during the previous cycles of the universe had been prevented.

"Barkalov has been killed", Academician Matveyev reported to the academic board. "But he had not submitted meekly to the course of events as something established once and for ever. He managed to interfere with it and reverse it. He hadn't been able to complete his new theory. But at the price of his life he saved for the future the lives of hundreds of people who can create much more than one person can. And another thing I'd like to stress is that Barkalov has proved that people can prevail over the sequence of events and no matter what occurred during the previous cycles, our future depends on us alone. Then let us be optimistic!"

## Can Time Have Cycles?

The idea of "eternal recurrence", the "cycle of time", and so on, had been part of the ancient philosophies of Greece, India, China and the Middle East.

Arguments along similar lines are to be found in some current models of the universe. The idea of cyclic time "closed upon itself" has been gaining currency.

In his *Dialectics of Nature*, Friedrich Engels wrote:

"When we say that matter and motion were not created and cannot be destroyed we say that the world exists as eternal progress... another question here is whether this process constitutes some eternal repetition of one and the same event in the form of extended cycles, and if so, whether these cycles have upward and downward branches."

In 1949 the well-known mathematician Kurt Gödel read his paper on time in the general theory of relativity at Princeton University where Einstein was then working. In it Gödel argued the possibility of closed geodesics for some models of the universe. To put it in the layman's language, this means that in certain circumstances the universe may keep returning to its original state and in the future repeat the past cycles exactly time and again.

If such were really the case, it would mean that the universe should in future stop expanding and begin contracting to gain infinitely great density. After that another expansion should set in, during which the same space objects would evolve. At some stage the earth would make its appearance, and on it the same events would be repeated, the same people would be born to live the same lives, as their twins in the preceding cycle. And so it would go on endlessly.

Einstein heard Gödel's paper but it is hard now to say exactly what his reaction was. His contemporaries had divergent views about it. According to some, Einstein remarked during the debate on Gödel's paper that he did not like the conclusions drawn in it, and according to others, he showed a degree of appreciation.

Years later the distinguished American theorist S. Chandrasekhar examined Gödel's model once more and arrived at the conclusion that the closed trajectories it proposed lacked physical sense. It should be noted, however, that Chandrasekhar's idea of "physical sense" cannot be regarded as completely objective.

In the final analysis the point is not whether Gödel's model is correct. It can only be a limiting case anyway. Other models exist which agree with the equations of the theory of relativity and also contain closed geodesic lines.

The fact that Gödel's idea of a recurring past is impossible according to Chandrasekhar does not rule out such a possibility within the framework of the general theory of relativity. It would, of course, be significant if it were possible to prove the impossibility of closed timelike lines also for a general and not only limiting case, but at this stage it can only be said that Gödel's idea for a limiting case is not correct. In other words, it is yet to be proved that a world with closed time cycles cannot exist in reality.

It goes without saying, that the situation created in the story is wholly fictitious. Even if the universe is indeed passing through stages, shaped by similar conditions, it is extremely hard to suppose that the concrete circumstances would repeat themselves. Such a thing could probably be imagined from the standpoint of classical physics which restricts all the diversity of natural events to the rigid connection between cause and effect. Modern science, however, has produced convincing proof that chance events have a very important role to play in the evolution of matter. While such events cannot change the general trend of the evolution, they may affect concrete situations arising in nature.

The same is true also of the activities of intelligent beings. In the story the chance event is represented by the actions of the main character, Barkalov.

## Is Our Universe the Only One?

During the last few years physicists and astrophysicists have increasingly been attracted by the idea of multiplicity of the universe, or the probability of many different worlds. They reason that apart from our universe, the material world can hold numerous other universes possessing different properties and bordering on one another in various intricate ways.

If we arrange all objects of nature according to size we will have a logical sequence—from elementary microparticles to galaxies, and finally, to the Metagalaxy. This order is suggested by our notion of how a part is related to a whole, that is, by our common sense. Classical physics was always guided by the principal conception that any complex object or phenomenon consists of simpler elements or events. That was what its common sense amounted to. But common sense is not always a reliable basis for scientific conclusions, especially in cases where fundamental laws of nature are concerned.

One such area is the physics of the microworld. Recent studies of processes developing at a microscopic level have revealed astonishing facts. It has been found, for example, that an elementary particle may consist of several similar particles. The proton decays for a very short time into another proton and pi-meson and every pi-meson decays to release three more pi-mesons. Moreover, having released a pi-meson, the proton may transform into a heavier neutron.

Thus common ideas about the simple and the complex, a part and a whole, undergo paradoxical changes in the microworld: a part may turn out to be more massive than a whole and no less complicated in structure.

The notions of "big" and "small" are being currently revised also at the megacosmic level, true, on a purely theoretical basis so far.

According to the general theory of relativity, the greater the mass of a body the more pronounced the warping of space around it. If a great mass is concentrated in a small volume, it may collapse to form a black hole, an object from which neither a particle nor a photon can escape. But if the mass of the collapsing body has an electric charge and even if this charge is as small as the charge of an electron, the black hole cannot be completely isolated from the outside universe. The lines of force of the electrostatic field must escape outside and close on another charge. Instead of a massive body a hypothetical outside observer will see only a tiny wormhole connecting our universe with some other universe whose warped space is almost closed around the given body. But what is truly amazing is that the wormhole will look exactly like a common elementary particle. Taking this hypothesis to its extreme logical conclusion, it can be assumed that our observer may take a whole universe to be just a particle, say, a proton or electron.

The question may then arise: Could all the known elementary particles be whole universes perhaps? Could all those other universes simply behave like elementary particles in our own universe?

Such a hypothetical situation was described by the well-known Soviet physicist, Academician Moisei Markov, several years ago. His theory is that at the microscopic (quantum) level the world consists of countless other, constantly changing worlds connected among themselves by infinitely complex relationships which cannot be explained on the basis of the space-time relationships characterizing our universe. The structure of such worlds is not clear, although the possibility of them existing in our universe does not contradict the laws of nature known to physics today.

If Academician Markov is correct, then a smaller object can contain a bigger one. If an elementary particle, say, an electron is only a small observable part of a gigantic universe, then our universe actually consists of numerous other universes. And this is true not only of the universe, but of any object in it, man included.

Thus in the light of this hypothesis our world is not a sequence of smaller objects inside bigger ones, but a system consisting of mutually penetrating and mutually conditioned worlds in which phenomena on the megacosmic and microcosmic levels are interconnected and exist in unity.

## In Lieu of Conclusion

# The Revolution Is Put Off (Science fiction)

The small disk of the sun descended almost to the very horizon and turned deep reddish-violet. Everything on this planet looked unnatural to the human eye. But those red-and-purple sunsets were the worst. They made you despondent.

True, Clay was not one of those to become despondent. Not in the least. The two years of his first round of duty service in space had not been enough to kill his curiosity for anything out of the ordinary.

Clay was slowly walking up the path leading to the squat house which was their base. He was carrying a small dark-coloured sphere, a little bigger than a billiard-ball, in his hands.

Finally he reached the porch and went up the stairs heavily, panting as though he had been doing some really hard work. He entered the inner room and, shutting the steel door behind him, lowered the sphere to the floor.

The sphere emitted a long and mournful ringing.

Ferry stirred in his bed.

"Brought some more junk?" he drawled lazily not turning his head.

"Just take a look!" Clay exclaimed excitedly. "A little thing like that and weighs 25 or 30 kilograms!"

"How can you bother with all that garbage so much?" Ferry spoke as indifferently as before, still lying with his face to the wall.

"Garbage?" Clay was outraged. "But it was left by Them!"

"All this has long been studied—without us," Ferry said in a bored voice.

"And what if not all?"

"What a pest, for Christ's sake!" Ferry grumbled.

He groaned, sat up and put his feet on the floor.

"Well...?"

Clay squatted down and stroked the round object as if it were a kitten.

There was really something unusual about it. It was made from a strange material, which looked neither like metal nor polymer; it seemed to be transparent but it was impossible to see what was inside it. Its surface was shimmering and it had some sort of a blurred design which kept appearing and fading all the time.

"Do you see it?"

"See what?" Ferry asked unimpressed. "It's just a ball."

"You're a funny chap, Ferry, really. Nothing surprises you, nothing gets under your skin." Clay was peeved and his dark eyebrows were knitting.

"But is there anything left in the world to be surprised about?" Ferry grinned teasingly. "Especially here on this God forsaken planet from which even the natives have cleared out?"

Clay snorted contemptuously.

"Everything has long been sorted out," Ferry went on with a sigh. "Not a single riddle left. Not a single sensation. Nothing to strike one's imagination."

"It's risky reasoning. It can land one in a silly situation," Clay remarked.

"Frankly speaking, I'm interested in one thing only," Ferry said putting a stop to the argument, "and this is how many more days do we have to stick it out here."

"But I enjoy being on this planet," Clay said.

"Once I was also like you. I wonder what you'll say after the fifth round. You'll be fed up with it, have no doubts about it".

"No!"

"All right, all right," Ferry said in a reconciliatory tone. "Put your sphere away and let's get down to business. It's supper time."

Clay gave in and kicked the ball lightly with his toe to where a pile of all kinds of things was accumulating in a corner. The ball emitted a hissing sound and, describing a few zigzags around the room, ducked under the bed. Ferry was at the door in two leaps.

"Idiot! What if this is a mine?" He jumped on Clay.

"Doesn't look like it," Clay said undisturbed.

"Who knows," grumbled Ferry casting a nervous glance at the bed under which the hissing and crackling noises could still be heard. "What am I supposed to do with it?"

"When I found it it also hissed for a while but then quieted down."

The noises stopped gradually.

"Now listen," Ferry began with resolution. "To hell with it! I'm going to take it to the storage block immediately, whatever you say. We'll be safer."

He went to the bed, kneeled down, extended his hand and touched the ball fearfully.

Nothing happened. Ferry tried to get it out, but could not even move it as though it were rooted to the ground.

"What the hell?"

"It doesn't like the idea of going to the storage," Clay laughed.

The same moment, as if in response to Clay's words, the sphere started up, went right beneath Ferry's hand, rolled to Clay's feet, rubbed itself against his shoe and dashed back under the bed.

"What do you think, Ferry, could it be..."

"What?"

"Could it be intelligent?"

"Rubbish. The inhabitants of this planet were creatures with two arms and two legs. It's an established fact."

"It looks as if it understands something... Better leave it in peace."

"OK, let it be," Ferry consented grudgingly.

He began to lay the table for supper, casting an anxious look in the direction of the bed every now and then. But the ball was quiet.

"What do we have here today?" Clay asked with interest as he sat to the table.

"First course—thirteen stroke three," Ferry began. "Second course..."

A pained look came into Clay's face.

"You and your baker's dozen..."

"Are you superstitious or something? It's the choicest delicacy."

"How can you say such a thing, Ferry? We've had this 'delicacy' every other day, in fact, every time you've been on duty."

"Would you prefer a beefsteak? Rare perhaps?"

Clay rolled his eyes dreamily.

"Half a galaxy for a piece of meat."

"You know what," Ferry began but choked over his food gaping at the table. "What the hell is this?"

Clay followed his stare and jumped from his stool, crashing it to the floor.

A big hunk of meat, fried nice and brown and smelling deliciously, lay on the plate before him.

Clay touched it with one finger cautiously.

"Meat..."

"Nonsense. Where could it come from?"

"I don't know, but it's meat."

Clay pulled a clasp-knife from his pocket and cut himself a small piece. Reddish juice was oozing on the plate. He picked the piece with the knife, bit off a little and began to chew.

"Meat!" He bellowed. "Real meat, I'll be damned!"

Ferry, who was watching him tensely, snorted.

"Meat? The darned planet. Hallucinations is just what we need."

"Hallucinations like hell!" Clay shouted. "I tell you it's a beefsteak and as good as they make them! Can't you see yourself?"

"Of course I can see but it doesn't mean anything. Optical illusion, that's all."

"Illusion? Then touch it!"

Clay extended the knife with the piece of meat on its tip across the table.

Ferry made a wry face and felt the meat between two fingers gingerly.

"Well isn't it meat?" Clay asked.

"I see it's meat, but who can guarantee it isn't an illusion all the same?"

"I'll shove it down your throat so you'll know what it is," Clay said irritably.

But Ferry had already pulled the piece of meat off the tip of the knife and put it in his mouth. He was chewing the meat for a long time, savoring it, smacking his lips and pausing for breath every now and then.

"Have you been convinced?"

Ferry shrugged:

"What should I have been convinced of? What did I feel after all? Something hot on my tongue and tasting like meat, but that was nothing but my sensation. No, it's not meat."

Clay burst out laughing.

"Fine then, old man. There'll be more left for me".

He moved his stool up to the table and fell upon the beefsteak with relish. Ferry also took his seat and muttering under his breath, began eating his favourite "thirteenth" dish.

"Ah, that was wonderful!" said Clay having finished with the beefsteak.

"In your place I wouldn't have ignored the thirteenth either."

"Why?" asked Clay, "I've had enough."

"Just because illusions are not very nutritious even when they are edible."

Clay looked at him with pity.

"Do you still think that piece of meat was an illusion?"

"Naturally, what else could it be?"

"But you said illusions cannot be nutritious and I'm full."

"Being full is also a sensation and so can be deceptive."

"But the meat was real."

"This means you believe in God."

"How's that? What's God to do with it?"

"How else? We've just witnessed a miracle. Before our very eyes a piece of meat materialized out of nothing. It's mysticism."

"What rot! You've gone quite savage here, it seems, so much so that you forget Einstein."

"Why Einstein?"

"Oh, for God's sake! Just because mass depends on velocity. If two particles are properly accelerated they can make a whole galaxy, let alone a beefsteak."

"Granted," Ferry conceded in a tired voice. "But since when do atoms know how to join each other to make a good fried piece of meat? The probability of such an event is of the order of minus one hundred-thousandth power of ten. Zero practically."

"You're right, of course, if you ignore the fact that the beefsteak looked exactly like I imagined it."

"Splendid! This means you are God?"

"The devil take you!" Clay laughed. "You've made a great discovery, but of course God shouldn't mention the devil."

"Don't worry it is within your power to give yourself absolution."

"Yes, that's true. But I'm not sure I can work miracles."

"Why not try?"

"Why not, really? But what kind of a miracle?"

Clay searched the room with his eyes.

"What's the difference?" Ferry stretched out in an arm-chair, and crossed his legs. He was quite complacent, as usual after supper. "It's all the same for one who can work wonders whether to create or destroy something..."

"Say, that's an idea!" Clay seized on Ferry's words and a mischievous expression came into his face. He looked at Ferry with narrowed eyes:

"Let's try then. Let the armchair in which you are sitting disappear."

Nothing happened.

"Too bad! You must do better than that," Ferry laughed.

He stopped short and started fidgeting. Something was happening to the armchair: it had begun folding up grotesquely, its legs lifted into the air and it began to fade...

"Hey!" Ferry bellowed but it was too late. The armchair had melted away completely and he crashed to the floor.

"Good God!" Clay was flabbergasted.

"What the hell do you think you are doing?" Ferry was rubbing his bruised elbow furiously.

Clay had recovered himself.

"Has anything happened?"

"You ask me?!"

"Oh, yes, I forgot. You fell and bruised yourself. But it's only your subjective sensation."

"Stop it, or..." Ferry began menacingly but fell silent taking note of the empty place where the armchair had stood only seconds before.

"Ridiculous!"

"So that's how it is," Clay remarked with some satisfaction and proceeded to destroy the table.

Ferry only snorted.

Clay was enjoying himself thoroughly: he destroyed the table, then a stool, then another, then a bedside table and then recreated one stool.

"Hey, wait!" Ferry cried. "Enough of his nonsense!"

"What's wrong?"

"You have no imagination whatsoever, that's what. Create—destroy, destroy—create, just like a kid. It's becoming boring."

"There's a kid in every one of us," Clay said.

"But still you could think up something more interesting."

"All my life I've dreamed about a magic wand," Clay went on, paying no attention to Ferry. "It looks like I have it now but I can't think of anything special to do with it. If only I had this kind of toy when I was a boy."

"It's a toy to some, but to others..."

"What about your precious logic now?" Clay wouldn't leave Ferry in peace. "How do you explain all this? Something has happened that contradicts all laws, correct? But since all laws have already been discovered, as certain individuals assert, then we must recognize the existence of something standing above the laws. What do you say?"

"I say that you are right."

"What? Are you serious?"

"I'm not in the laughing mood at all, Clay."

"Oh, keep your shirt on! It must be some new paradox."

"Paradox, my foot. Clay—a worker of wonders. Could you write a formula, perhaps? Enough of it, I've had all I could take. I'm going back to earth to become a missionary. Start flying from planet to planet, telling about miracles. And I'll take you along as a living demonstration."

"Why not?" Clay straightened up, hands on hips. "I won't let you down, but you'll have to avoid mentioning the devil so much."

"Maybe the devil is the whole point, who knows?"

"Maybe, I don't know. One thing I know is I'm pretty good in the supernatural."

"By the way, how do you do it?"

"Very simple. I just try to imagine the thing I want very clearly and create the vision in my mind. That's all."

"Oh, hell! Look!" Ferry cried out suddenly.

Clay saw the ball lying at the very wall where the bed had been. It had puffed itself out to the size of a football and was pulsating and scintillating with a greenish lustre.

Clay went up to the ball and leaned over it: "Was all this your job?"

The green inside of the ball turned ruby-coloured immediately. The ball detached itself from the floor, jumped about a metre and a half into the air almost grazing Clay, hovered above for a moment, then descended and turned green once more.

"What's this?" Clay said weakly.

"It's meant as a confirmation, I suppose. Or denial, for that matter."

"Mm-yes," Clay was still regarding the ball thoughtfully. "I have an idea!" he exclaimed suddenly.

He went closer to the ball.

"If you meant 'yes', then destroy..."

He looked around the room only to find that it was practically empty. His glance lingered on Ferry's face and a look of mischief came into his eyes.

"Don't you even think about it!" Ferry sounded really scared.

"Why not?" asked Clay innocently, "I'll 'recreate' you afterwards."

"Yes, I know, it will be your own idea of me. It won't be the same Ferry. No, thank you."

"OK, relax," Clay relented, and turned his attention back to the sphere.

"If that was 'yes', then let there be a table again."

The table was back the next second.

"Now we must find out what represents 'no' and we can play a game I used to enjoy very much when I was small. It was based on 'yes' and 'no' answers."

"It shouldn't be difficult to find out," Ferry said and crossed the room to where Clay was standing near the ball.

"What will you do for a 'no'?"

The ball remained motionless and only changed its colour from green to a poisonous yellow.

"What was all this about, witchcraft?" he inquired describing a wide semi-circle around the room with his hand.

The yellow colour became even more poisonous.

"Now you see how wrong you were when you deplored the fact that there could be nothing new in the world. The inhabitants of this planet knew a thing or two more than we do," Clay said.

"Be quiet," Ferry commanded and again turned to the ball:

"Does this mean that there are natural laws we—he and I, science on earth, that is—do not know?"

The ball turned scarlet.

"And everything that went on here was subject to those laws?"

The ball blinked a ruby-coloured light.

"Goodbye, missionary," Clay laughed. "You'll have to give up your views once more and get down to the business of overthrowing modern physics."

"Stop it!" Ferry winced, "better think of how we could get all that information. Could we get the relevant information?" he turned to the ball once more.

It turned yellow.

"You put your question in a wrong way, Ferry."

"You're right of course, but that was because of my disappointment."

"I think I'm beginning to understand. It was programmed that way by those who lived here before."

"Thanks for the explanation. I still hope I could have gone this far unassisted. But why? Why wouldn't they share their knowledge?"

"Probably it's because laws of nature are not given out free. You are expected to go all the way yourself."

"Then why all this mystification?"

"I don't know, perhaps it's intended to destroy our selfassurance, your habit of thinking in absolute terms."

"We'll have to take it back to earth and see what's what," Ferry decided.

The ball was radiating yellow light.

"It doesn't want to go to earth," Clay commented.

"What do you mean 'doesn't want'? It's only a machine after all."

The ball became dazzlingly yellow.

Ferry took a step in its direction.

The ball quivered.

"Beware, Ferry!" Clay cried.

"I don't care." Ferry reached his hand for the ball.

That same moment the yellow light went out. The sphere sprang from its place, dashed past the two men, rolled to the closed door, went right through it and was gone.

Clay and Ferry exchanged a stupefied look and stared at the door which was intact.

"Damn it," Ferry muttered. "It's twenty centimetres of titanium steel!"

"I would do the same thing in its place," Clay was sufficiently recovered to go on with the endless argument.

"It's a pity in a way," Ferry sighed. "We haven't learned anything." Then he smiled: "The revolution in physics is put off."

"No, you're wrong. We have learned something, and not so little at all," Clay objected.

"What about?"

"We've learned that this revolution is inevitable. And that's something."

This story should not be taken to mean that anything can happen in nature and that the science of the future will have the power to explain even the impossible. What is meant is that the external world is infinitely diverse and inexhaustible, and that science will never be able to claim it knows everything.

Our knowledge will always be incomplete and, in the words of Academician G. I. Naan of Estonia, the path of scientific cognition is a race-track without a finish.

The universe is an inexhaustible source of knowledge. But the more we know, the deeper we realize the extent of what is yet unknown and the greater the probability of stunning discoveries.

Knowledge is obtained through unabating scientific quest in the interests of civilization and its vital requirements. This quest is not indiscriminate, its orientation being dictated by practical needs.

We cannot rule out the probability that there really exist in the universe highly developed civilizations which have surpassed us in the amount of knowledge obtained. However, we must not let our hopes for the future hinge on the fantastic probability of exchange of information with other intelligent inhabitants of the universe. It is yet to be seen whether we will be able to understand each other or whether we will be able to find such inhabitants in the first place.

The level of development achieved by the terrestrial civilization and its scientific and technological achievements are convincing proof that, given the essential social conditions, humanity can solve the most complicated problems by itself, without outside help.

The developments of the latter half of the 20th century, and especially of the last two decades, in astronomy alone have brilliantly confirmed this fact. New methods of astronomical research, and first and foremost, the development of space engineering, which has made astronomy an all-wave science, have radically changed our notions of the universe.

Early this century both the universe and almost all of its space objects were thought to be stationary and unchanging. Their evolution was considered to be a very slow and smooth process which led from one stationary state to another.

These views underwent a revolutionary change. It was established that the universe was non-stationary and expanding. Then came the discovery of violent, explosive processes accompanied by the generation of great energies. It became clear that not only the universe as a whole was undergoing a change and that its past was different from its present and the future, but also that non-stationary events leading to profound qualitative changes were taking place at all levels of the existence of matter.

Accordingly, astrophysics had changed into an evolutionary science preoccupying itself both with the study of the present state of space objects and with the laws governing their origin and development. A thorough knowledge of these laws enabled it to predict the future states of the planets, stars and galaxies, the importance of which is invaluable both to theory and to practice.

20th century astronomical discoveries and the change they have made in our views of the universe can truly be regarded as a revolution in astronomy, which is an integral part of the general scientific and technological revolution spreading to all areas of modern science and its practical applications.

Although it can be supposed that the current astronomical revolution is nearing completion, this does not at all mean that we should expect no new discoveries. New data being accumulated at present, especially those obtained by means of space probes and orbital stations, give us every reason to expect new extraordinary discoveries. This process never stops in fact. For example, it has been found recently that sizable areas of the universe appear to contain no galaxies which are a major feature of outer space. According to new data the galaxies making up the so-called super-clusters of galaxies are mainly situated along the "walls" of cells contained in gigantic "honeycombs", not unlike those built by bees. The length of one side of such a cell is something like 100 billion light-years, and it seems there are no galaxies in the space contained between the sides. By now several such "vacancies" have been discovered and some of them account for vast areas.

One of the areas free of stars and galaxies is 300 billion light-years across. To draw this conclusion astronomers studied the distribution of galaxies along three straight lines stretching in three different directions. They found that space was packed with galaxies up to a distance of 500 billion light-years, that there were evidently no galaxies from that point all the way to 800 billion light-years, and that after this boundary the number of galaxies was again large.

Great effort is yet required to establish with finality the exact distribution of the tens of thousands of far galaxies. The final results will be of great importance in solving many major issues of astrophysics, especially in establishing the origin of the galaxies.

The "vacancies" discovered in the universe agree well with the theory of the origin of galaxies on which Academician Yakov Zeldovich and his colleagues are working at present.

The study of the structure of outer space is closely associated with measurements of the distances to far galaxies. Great possibilities in this area have been provided by the development of X-ray astronomy. The hot intergalactic gas in the clusters of galaxies is one of the sources of X-ray radiation. X-ray studies have revealed clouds of intergalactic gas to have the form of extended nebulas.

It has been established that the electrons of intergalactic gas interact with elementary particles in the residual background radiation. This fact makes it possible, by comparing data of radio and X-ray observations, to determine not only angular but also absolute dimensions of the X-ray nebulas. Once these dimensions have been evaluated, it will become possible to calculate the distances to far objects by simple trigonometric calculations.

Intergalactic gas may therefore provide the long-awaited standard for measuring cosmic distances.

Studies carried out from on board spacecraft are invaluable in that they open up vast opportunities to settle long-outstanding questions. One of them is determination of the mean density of matter. Progress in this area will largely depend on the results of infrared and X-ray observations of outer space.

In principle, the density of matter in space can also be determined on the basis of gravitational fields. A galaxy or any other extended space object is seen from earth at an angle, the value of which depends on distance: the farther the object, the smaller the angle. According to the theory of relativity, the presence of a strong gravitational field in the space between the observer and the object observed causes light waves to deflect, and by the amount of this deflection it is possible to determine the mass of the matter generating the gravitational field. But to do this it is also essential to be able to measure cosmic distances accurately. We have just discussed one way of measuring them. Another way is by means of radiotelescopes stationed at sufficiently large distances from one another and put into space orbits. Technically this has been proved feasible by the deployment of the KRT-10 radiotelescope on the Soviet *Salyut 6* orbiting station. Judging by the rapidly accumulating data of astronomical observations, it seems we are on the verge of a new qualitative change in our knowledge of the universe. This change may be expected in the nearest future.

# SCIENCE FOR EVERYONE

Written in a language easily accessible to a wide readership, this book is an exposure of some extraordinary discoveries in modern astronomy and of the puzzling problems it still has to solve. It is also a presentation of facts defying traditional views, of original theoretical conjectures and new research methods. Debatable astronomical issues are set out in a lively and interesting form, and in conformity with the latest achievements in physics.

ИЗДАТЕЛЬСТВО · МИР ·